Open File Report OF85-6

The Vegetation Geochemical Signature of the Agassiz Stratabound Au-Ag Deposit, Lynn Lake, Manitoba

By M.A.F. Fedikow

Manitoba
Energy and Mines
Geological Services

1985

CONTRIBUTION TO PROGRAMMING CONDUCTED UNDER
THE CANADA-MANITOBA INTERIM AND MINERAL
DEVELOPMENT AGREEMENTS

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Energy and Mines

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
GEOLOGY, PHYSIOGRAPHY AND VEGETATION	2
FIELD METHODS, SAMPLE PREPARATION AND ANALYSIS	8
RESULTS	10
Descriptive Statistics and Data Comparison	11
Single Element and Element Ratio Profiles (Line 6554)	13
Contoured Data	23
Black Spruce Needles	23
Copper	23
Lead	25
Zinc	26
Iron	26
Manganese	27
Ash	27
Black Spruce Twigs	31
Gold	31
Arsenic	31
Inter-Element Associations	32
DISCUSSION	34
CONCLUSIONS	39
ACKNOWLEDGEMENTS	40
REFERENCES	41

APPENDICES

Appendix 1: Raw Analytical Data and Duplicate Sample Reproducibility	45
Appendix 2: Cumulative Frequency Plots	62
Appendix 3: Part 1: X-Y Element and Element Ratio Plots	67
Appendix 3: Part 2: Element Ratio Plots (Line 6554) - Agassiz Black Spruce Needles and Twigs	84
Appendix 4: Spearman and Kendall Correlation Coefficient Matrices	93

TABLES

Page

Table 1: Major species in bog and boreal forest environments, Agassiz stratabound Au-Ag deposit vegetation geochemical sampling area, Lynn Lake. 7

Table 2: Summary of descriptive statistics for analyses of black spruce (Picea mariana) needles and twigs, Agassiz stratabound Au-Ag deposit, Lynn Lake. 12

Table 3: Summary of descriptive statistics for analyses of surficial deposits, Agassiz stratabound Au-Ag deposit area, Lynn Lake. 14

Table 4: Summary of Spearman and Kendall correlation coefficients for significant element pairs in black spruce (Picea mariana) needles and twigs, Agassiz stratabound Au-Ag deposit vegetation geochemical study area. 33

FIGURES

Figure 1: Location map for the Agassiz vegetation geochemical study area. iv

Figure 2: Simplified regional geology of the Lynn Lake greenstone belt. 3

Figure 3: Detailed geological setting of the Agassiz stratabound Au-Ag deposit, Lynn Lake. 4

Figure 4: The gradiometric signature of the Agassiz Metallotect. 5

Figure 5: Vegetation geochemical sample location map for the Agassiz study. .....(in pocket)

Figure 6: Variation in concentration of Cu and Pb in ash of black spruce (Picea mariana) needles from line 6554 over the Agassiz stratabound Au-Ag deposit. Section looks west. 15

Figure 7: Variation in concentration of Zn and Fe in ash of black spruce (Picea mariana) needles from line 6554 over the Agassiz stratabound Au-Ag deposit. Section looks west. 16

Page

Figure 8: Variation in concentration of Mn and Ash in black spruce (Picea mariana) needles from line 6554 over the Agassiz stratabound Au-Ag deposit. Section looks west. 17

Figure 9: Variation in concentration of Au and As in black spruce (Picea mariana) twigs from line 6554 over the Agassiz stratabound Au-Ag deposit. Section looks west. 18

Figure 10: Variation in concentration of Fe (expanded scale) and Cu x Pb x Zn/Mn in black spruce (Picea mariana) needles from line 6554 over the Agassiz stratabound Au-Ag deposit. Section looks west. 20

Figure 11: Histograms for Zn, Fe, Mn and Ash in black spruce (Picea mariana) needles from the Agassiz stratabound Au-Ag deposit vegetation geochemical study area. 21

Figure 12: Histograms for Cu and Pb in black spruce (Picea mariana) needles and for Au and As in black spruce twigs from the Agassiz stratabound Au-Ag deposit vegetation geochemical study area. 22

Figure 13: Contoured Cu and Pb contents in black spruce (Picea mariana) needles over the Agassiz deposit. 24

Figure 14: Contoured Zn and Fe contents in black spruce (Picea mariana) needles over the Agassiz deposit. 28

Figure 15: Contoured Mn and Ash contents in black spruce (Picea mariana) needles over the Agassiz deposit. 29

Figure 16: Contoured Au and As contents in black spruce (Picea mariana) twigs over the Agassiz deposit. 30

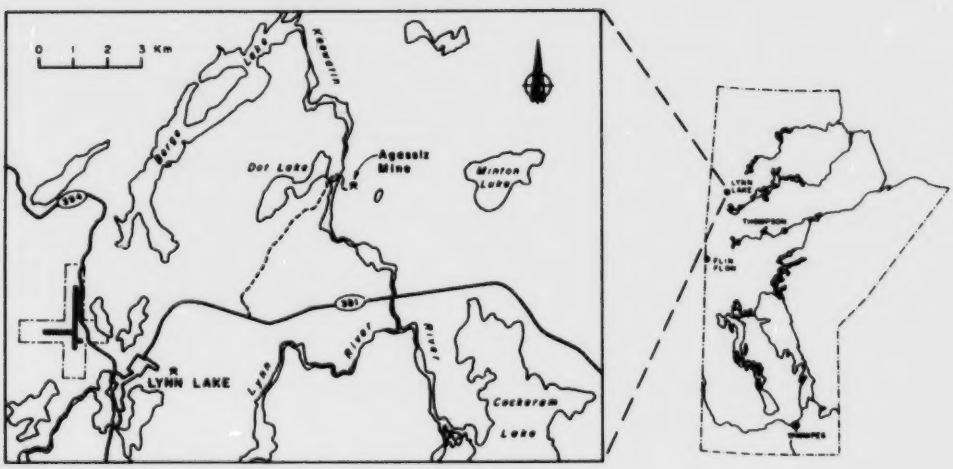


Figure 1: Location map for the Agassiz vegetation geochemical study area.

INTRODUCTION

This vegetation geochemical study at the Agassiz stratabound Au-Ag deposit (Fig. 1) was undertaken in response to the preliminary results of biogeochemical orientation surveys conducted in the Lynn Lake area (Fedikow, 1984). The results of the orientation survey at the Agassiz deposit and at one other location west of the deposit (Rushed Showing) along the Agassiz Metallotect indicated anomalous concentrations of Zn and Mn in needles and As in twigs of the black spruce (Picea mariana) growing over the mineralized zones. In addition, less diagnostic anomalies in Cu, Pb, Fe and Au in these plant organs were observed; the Zn, Mn and As anomalies were determined to be significantly larger than the mineralized zones. Labrador tea was also investigated during this survey but the trace element content in the leaves and twigs failed to reflect proximity to mineralization. As a result the sampling and analysis of Labrador tea was discontinued.

On the basis of the orientation survey results as well as the need to develop regional geochemical exploration techniques applicable to exploration for repetitions of Agassiz-type mineralization along the Agassiz Metallotect the Agassiz vegetation geochemical study was commenced. The results form the basis for this open file report.

The sampling procedures, analytical methods and the suite of chemical elements examined in this survey are consistent with those utilized in the orientation survey. These methods and procedures are mentioned only briefly in this report. For a more complete description including an overview of previously undertaken biogeochemical studies with respect to problems of mineral exploration the reader is referred to OF84-1 (Fedikow, 1984).

Analytical data and computer generated plots are presented in the appendices. Appendix 1 contains raw analytical data and duplicate sample reproducibility; cumulative frequency plots are presented in Appendix 2 and X-Y element and element ratio plots are included in Appendix 3. Appendix 4 contains correlation coefficient matrices.

GEOLOGY, PHYSIOGRAPHY AND VEGETATION

The regional geology of the Lynn Lake area has been described by Gilbert et al. (1980) and a short summary of that report as well as the local geology of the Agassiz deposit area is given in Fedikow (1984).

Briefly, the Agassiz deposit occurs within the Lynn Lake greenstone belt, an east-west trending sequence of Proterozoic Aphebian-aged volcanic and sedimentary rocks that have been assigned to the Wasekwan Group (Bateman, 1945). The Lynn Lake greenstone belt (Fig. 2) is divided into an older Southern Belt and a younger Northern Belt (Gilbert et al., 1980). The Southern Belt is characterized by tholeiitic, aphyric and porphyritic basalt overlain by discontinuous units of sedimentary rocks in the western portion of the belt and a variety of mafic, intermediate and felsic rocks elsewhere. The Northern Belt comprises mafic volcanic rocks of tholeiitic affinity interlayered with high alumina (>18% Al_2O_3) andesite and basalt. The Northern Belt contains the Agassiz stratigraphic sequence. The host rocks to the Agassiz deposit comprise a sequence of interlayered high-Mg basaltic rocks, siliceous and biotite-rich siltstones and oxide, sulphide and silicate facies iron formation (Fig. 3). This zone rarely exceeds 100-200 m in thickness. These rocks are overlain and underlain by sequences of aluminous (>18% Al_2O_3) fragmental basalts and mafic debris flows. This regional stratigraphic sequence has been named the Agassiz Metallotect and can be delineated by airborne (INPUT; Vertical Field Gradiometer) and ground (Ionization Potential) geophysical surveys, geological mapping and diamond drilling for a distance of approximately 65 km (Fig. 4). This metallotect is largely unexplored.

The Lynn Lake area is characterized by broad rolling topography of low relief in the southern portion of the area which becomes more subdued to the north. The northern portion, which includes the immediate area of this study is characterized by extensive sand, clay and bouldery muskeg deposits with some sand ridges. Outcrop in the immediate vicinity of the Agassiz deposit is rare due to a 1-5 m cover of sphagnum peat bog, glacial till and scattered inliers of glaciolacustrine Lake Agassiz clays. The ground over which this vegetation geochemical study was undertaken slopes

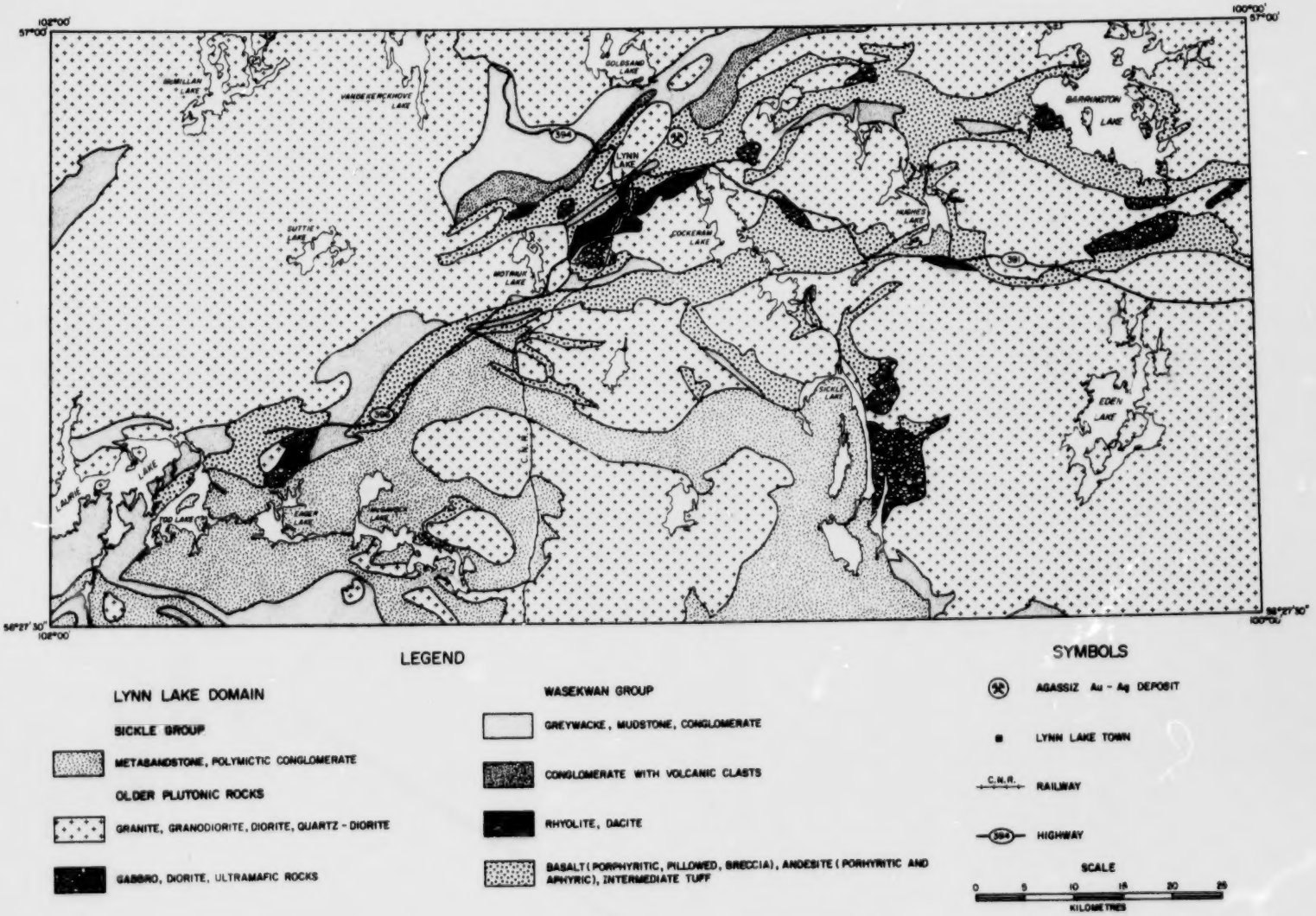


Figure 2: Simplified regional geology of the Lynn Lake greenstone belt.

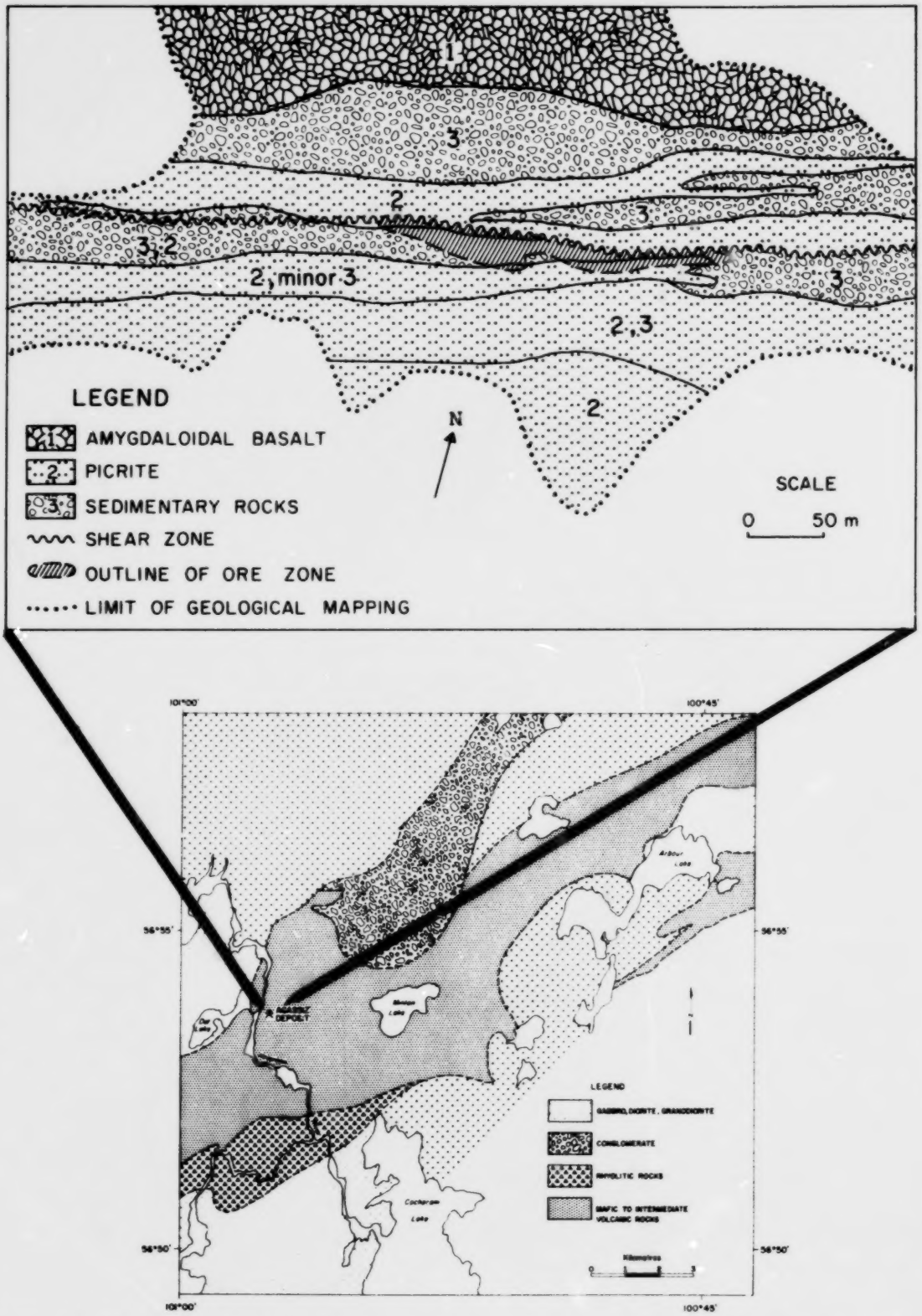


Figure 3: **Detailed geological setting of the Agassiz stratabound Au - Ag deposit, Lynn Lake.**

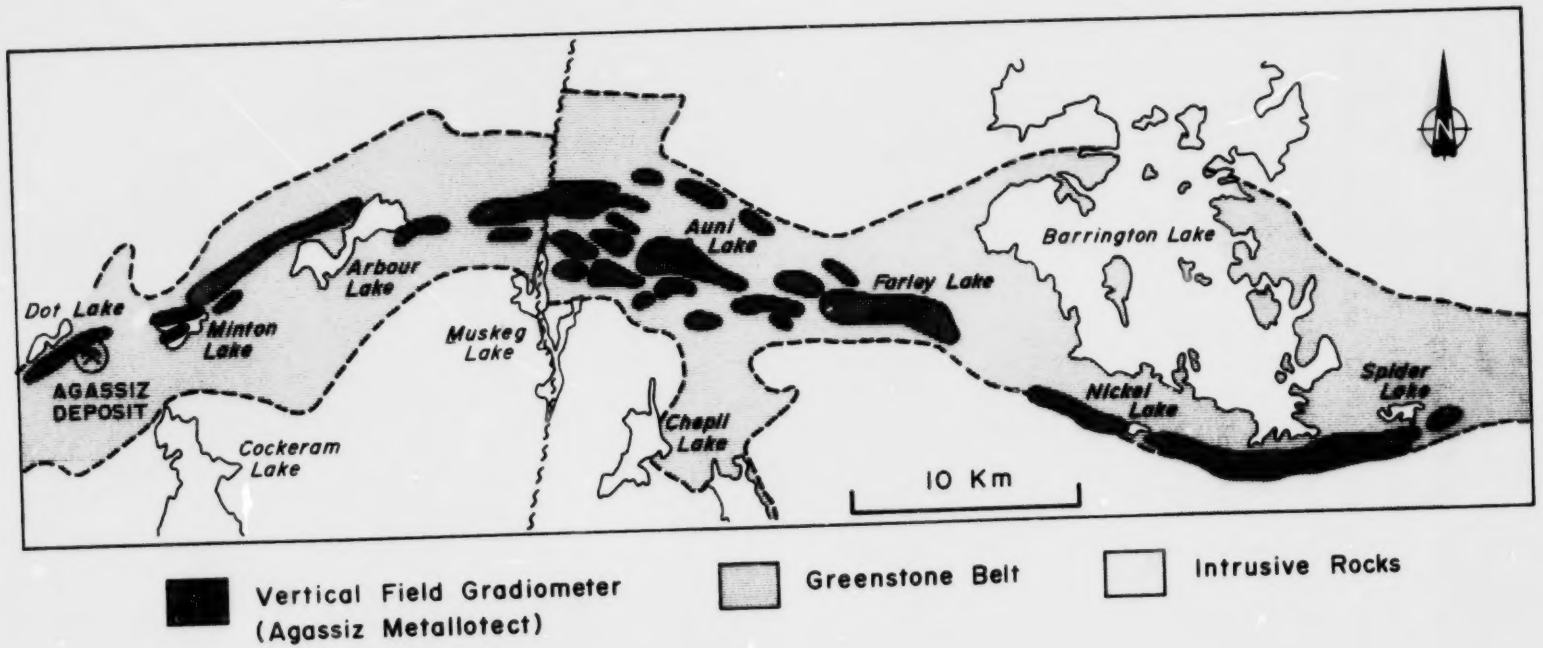


Figure 4: The gradiometric signature of the Agassiz Metallotect.

gently to the southwest proceeding from relatively well drained littoral sands and sandy till to poorly drained damp to wet sphagnum bog. The depth to permafrost is approximately 1 m. The boreal forest in northern Manitoba is characterized by several ubiquitous species of vegetation. Predominant among these is black spruce (**Picea mariana**), a fact which provides for sampling of this single species on both a local and regional basis. Lesser stands of tamarack (**Larix laricina**), pine (**Pinus divaricatum**) and birch (**Betula papyrifera**) are present in the study area. Vascular plants are predominated by Labrador tea (**Ledum groenlandicum**) particularly in the more poorly drained areas. Floral speciation of the bog and forest environments in the study area is presented in Table 1.

Table 1. Summary of major species in bog and boreal forest environments, Agassiz Au-Ag deposit biogeochemical sampling area, Lynn Lake.

Trees	Herbs
Picea mariana*	Epilobium sp.*
Betula papyrifera (F)	Arctostaphylos uva-ursi (F)
Larix laricina*	Vaccinium oxycoccus (F)
Pinus divaricata (F)	Vaccinium vitis-ideaus (F)
Shrubs	Ribes sp (F)
	Lycopodium (obscurum/annotinum) sp. (F)
Ledum groenlandicum (F)	Viola (pallens/renifolia) (F)
Vaccinium augustifolium*	Chimaphila sp. (F)
Vaccinium myrtilloides*	Urtica gracilis (F)
Alnus sp.*	Aster sp.*
Rosa sp. (F)	Cornus canadensis (F)
Acer spicatim (F)	Equisetum sp. (B)
Salix sp.*	Potentilla norvegicus/sp. (B)
Lonicera sp. (B)	Caltha palustris (B)
Carex sp. (B)	Carex sp. (B)
Grass sp. (B)	Grass sp. (B)
Corylus cornuta (B)	**Moss**
Kalmia polifolia (B)	
Betula glandifera (B)	Sphagnum (B)
Lichen	Mnium (B)
	Thuidium (F)
Cladonia fimbriata (F)	Polytrichum (F)
Cladonia mitis (F)	Pleurozium (F)
Cladonia rangifera*	Brachythecium (F)
Crustos green/grey*	Eurynchium (F)

Abbreviations are as follows:

F - boreal forest, B - bog. An asterisk indicates the flora occurs in both boreal forest and bog environments.

FIELD METHODS, SAMPLE PREPARATION AND ANALYSIS

Sampling of black spruce trees was conducted during a three-week period in June, 1983. The sampling was restricted to as short a time interval as possible in an exploration-oriented survey in order to avoid seasonal variations in the trace element content of plant organs (Guha, 1961; Cohen et al., 1985, Stednick et al., 1985). Trees of similar height and vigour were sampled at chest height (1.5 m); 20-25 cm lengths of branches with diameters not exceeding 6 mm representing 8 years of growth (2-3 cm growth per annum for mature black spruce) were collected. Branches on the north, south, east and west sides from each of 5 trees were sampled up to 5 m on either side of the transect at each sample site. The branches from each tree at each sampling site were then bulked to give 1 sample. Samples were collected every 3 m. This sampling procedure was undertaken to ensure (i) an adequate volume of twigs and needles for the various analytical procedures, and (ii) a representative sample at each site in order to avoid the problem of unequal trace element distribution throughout the tree resulting from the root specific supply of trace metals to various sections of the tree (Brooks, 1972). Effectively, root systems are responsible for supplying nutrients to specific portions of a tree with the result that high concentrations of trace elements originating, say, from a glacially derived heavy metal dispersion fan may be tapped by parts of the root system and missed by others. In this way, certain branches (needles and twigs) will contain anomalous amounts of trace metals while other branches from the same tree will approximate background. Therefore, it is possible that an anomaly can be missed by collecting only one branch from one side of a single tree at each sample location.

Using this sampling technique 368 black spruce samples were collected over the Agassiz deposit from 12 irregularly spaced transects oriented perpendicular to the host rocks for the gold and silver mineralization (Fig. 5). The transects were arranged in such a manner as to maximize sample recovery and to avoid an area of bulldozed alluvium over the central portion of the Agassiz deposit. The black spruce samples were prepared by first air drying in ventilated, labelled plastic sample bags for approximately 3 weeks and then the samples were separated into needle and twig portions, each stored

in clean cotton sample bags. The needles were macerated to -20 mesh using a Wiley mill, homogenized, and a representative split of 20 g ashed at 450°C in a muffle furnace. A fixed weight of ash (0.250 g) was dissolved using a hot HNO_3-HCl digestion and this solution was analyzed using AAS for Cu, Pb, Zn, Fe and Mn. The analyses were undertaken by Bondar-Clegg Ltd. (Ottawa). The instrumental neutron activation analyses (INAA) of Au, As and Sb were conducted by Nuclear Activation Services Ltd. (Hamilton) on 8 g briquettes of macerated twigs. The Au and As analyses are based on raw, unashed samples. Reproducibility of the analyses was monitored by collecting duplicate samples at every 10th site. The AAS analyses of duplicate samples falls within ±10% while the INAA are generally within ±20% although some analyses for Au were non-reproducible. Sb was consistently at or below the limits of detection in most samples and as such will not be discussed here.

RESULTS

The variation in concentration of Cu, Pb, Zn, Fe, Mn, Au and As in black spruce needles in twigs collected over the Agassiz deposit is discussed in this section. The data are compared with published average concentrations and also to the contents of these elements in humus, permafrost peat bog, and the $< 2\mu$ clay-sized fraction and heavy mineral (S.G. > 2.96) fraction of basal till samples collected in the vicinity of the Agassiz deposit. Single element and element ratio data are discussed with respect to changes in concentration in the needles and twigs with proximity to the Agassiz deposit. The interpretation of this data is based primarily upon contoured biogeochemical data with arbitrarily selected contour intervals after a simple form of data reduction. The range of trace element concentrations within the anomalies are compared with graphically determined threshold values. The role of the geochemical substrate at the Agassiz deposit as well as hydromorphic dispersion are discussed in light of the observed results. Inter-element relationships are discussed utilizing Spearman and Kendall correlation coefficients.

Descriptive Statistics and Data Comparison

A summary of descriptive statistics for Agassiz black spruce needles and twigs is presented in Table 2. Included in Table 2 are published data for average concentrations in plant ash (Hawkes and Webb, 1962; Brooks, 1972) and graphically determined threshold values for Agassiz samples using the technique of Tennant and White (1959). In the latter study the authors found that if the cumulative frequency of biogeochemical data is plotted on probability paper against either an arithmetic (linear) or logarithmic scale for concentration then the presence of two or more data populations will be suggested by a series of more or less co-linear points. If a line of best fit is drawn through the points representing each data population then the point of intersection of the two lines represents the threshold value for the anomalous population. A basic assumption is that one set of co-linear points represents the normal or background population and the second set of co-linear points represents the anomalous population. Diagrams illustrating the threshold determination technique are presented in Appendix 2. For comparison of Agassiz data with the tabled average values the Agassiz threshold is utilized and is taken to represent the upper limit of the background.

Examination of the data in Table 2 reveals that Cu, Pb, Fe and Au in Agassiz samples are significantly lower than the tabled average values whereas Zn and Mn are higher. It is difficult to assess these differences in that the average value is not vegetation specific, i.e., it is a general multispecies guideline for plants. Another consideration is that the average Au content has been determined in ash whereas Agassiz Au analyses are based upon raw sample INAA. Since ashing effectively increases the concentration of a particular element in the sample (see Steed et al., 1976) there appears to be no basis for comparison for Au between Agassiz samples and the average values. Furthermore, Au volatilization during ashing of biogeochemical samples results in Au loss rendering the average tabled Au analysis suspect. Regarding Cu, Pb, Zn, Fe and Mn contents in the Agassiz samples versus the average tabled contents the variability of the substrate (responsible for trace element supply to the plant) between Agassiz samples and those used kto calculate "average" values further precludes comparison between the two data sets.

TABLE 2

Variable	Range	Arithmetic Mean	Standard Deviation	Geometric Mean	Median	Average Concentration in Plant Ash	Threshold (graphical determination)
Cu	30-88	51	10	50	50	180	51
Pb	2-32	12	3	12	12	70	17
Zn	180-9000	1764(1739)	639(479)	1673	1800	1400	1850
Fe	450-14800	1008(944)	920(337)	910	840	6700	1030
Mn	0.5 - 10.0	3.6	2.2	2.91	3.4	4800	1.10
Ash	2.1-5.4	3.5	0.5	3.47	3.5	-	3.90
Au	0.1-3.8	0.67	0.45	0.56	0.50	7	0.55
As	0.08-8.70	0.28(0.24)	0.54 (0.1)	0.24	0.23	N A	0.25

Table 2: Summary of descriptive statistics for Cu, Pb, Zn, Fe (in ppm), Mn and Ash(%) by AAS in black spruce (Picea mariana) needles; Au(ppb) and As(ppm) by INAA in black spruce twigs, Agassiz Au-Ag deposit. Average concentrations for Cu, Pb, Zn, Fe and Mn in plant ash from Brooks (1972); Au average from Hawkes and Webb (1962). NA - not available. Bracketed values for Zn, Fe and Mn represent recalculated means and standard deviations after exclusion of highly anomalous outlier analyses. For black spruce needles n=292; for black spruce twigs n=309.

Table 3 summarizes some descriptive statistics for various surficial sampling media in the vicinity of the Agassiz deposit. The data for humus, permafrost peat bog and basal till are summarized from Nielsen (1983) and Fedikow (1984).

The concentrations of Zn and Mn in black spruce needles is very much greater than that in the remainder of the surficial materials whereas Cu, Pb, Fe, Au and As concentrations in the needles and twigs are lower than in the other surficial sampling media. It is difficult to make a detailed comparison between each of the sample types since corresponding samples of each type of material listed in Table 3 were not collected from the same sample location. Therefore, observations based on the correlation of chemical data between sample types can only be made in terms of the general patterns observed for the whole survey. This comparison is made in the following sections.

Single Element and Element Ratio Profiles (Line 6554)

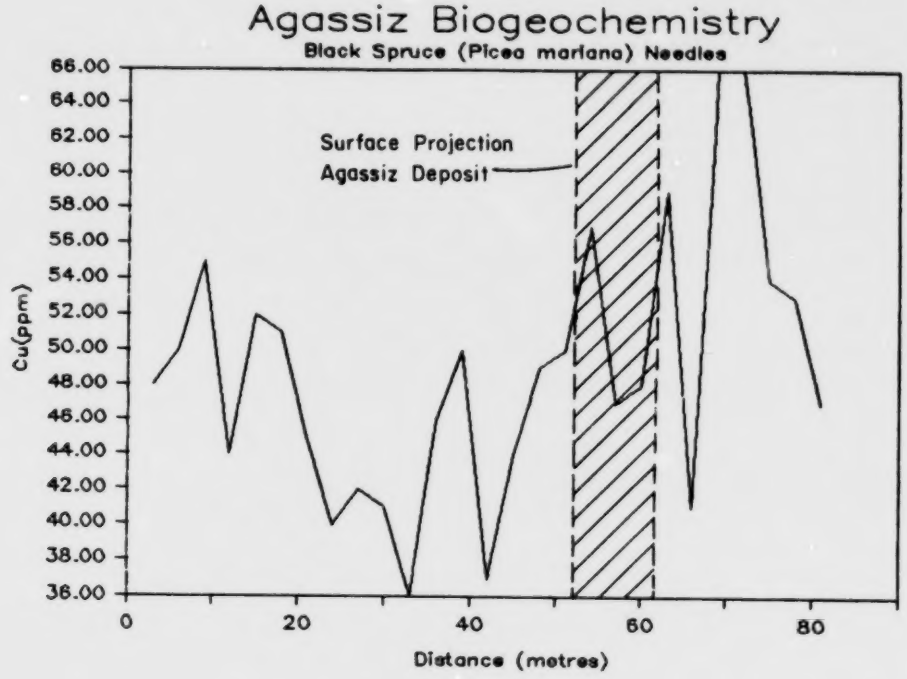
Trace element analyses for black spruce needles (Cu, Pb, Zn, Fe, Mn, Ash) and black spruce twigs (Au, As) are plotted for 28 samples from line 6554 over the West Zone of the Agassiz deposit (Fig. 5). The results for single element data are presented in Figures 6 through 9 inclusive and ratio data in Figure 10.

The concentrations of Zn (1600 to 2800 ppm) and Mn (1.0 to 5.5%) increase steadily in a downslope direction from north to south (Fig. 7 and 8) proceeding from relatively well drained humus and till cover to poorly drained, permafrost peat bog; Mn content proceeds without any apparent response to the surface projection of Agassiz mineralization whereas erratic Zn contents are observed with proximity to the deposit. Pb (16 ppm anomalous vs 8-14 ppm background) and Fe (1200-1800 ppm anomalous vs 800-1000 ppm background) indicate somewhat restricted anomalies of 30-35 m associated with the deposit (Figs. 6 and 7); the Agassiz deposit is localized in a "trough" of low ash concentrations (Fig. 8). Cu is non-diagnostic of the mineralization in these samples. Single element ratios were calculated as well as

TABLE 3

Variable	Black Spruce (BSW; n = 292) (BST; n - 309)	Basal Till Heavies S.G.>2.96 (n = 38)	Basal Till Clay-sized, < 2μ) (n = 38)	Peat Bog (n = 40)	Humus (n = 28)
Cu	BSW 30-88 (51)	5-50 (11)	38-242 (94)	20-2400 (190)	52-170 (90)
Pb	BSW 2-32 (12)	11-58 (18)	14-193 (45)	14-944 (88)	4-216 (27)
Zn	BSW 180-9000 (1764)	23-155 (41)	33-747 (149)	40-2000 (327)	14-84 (34)
Fe	BSW 450-14800 (1008)	1.6 - 3.1% (2.0)	2.8 - 8.9% (4.9)	-	-
Mn	BSW 0.5 - 10.0% (3.6)	365-1050 ppm (693)	110-1100 ppm (507)	42-4875 ppm (484)	27-3000 ppm (609)
Au	BST 0.10 - 3.80 (0.67)	3-15000 (1330)	-	1.27 (4)	0.1 - 9.4 (3.0)
As	BST 0.08 - 8.70 (0.28)	2.28 (6)	4-603 (107)	-	0.70 - 6.60 (1.88)

Table 3: Comparison of Cu, Pb, Zn and As (ppm), Au (ppb) and Fe and Mn (ppm and % as indicated) in black spruce needles and twigs with other surficial deposits in the area of the Agassiz deposit. Bracketed figure represents the arithmetic mean.



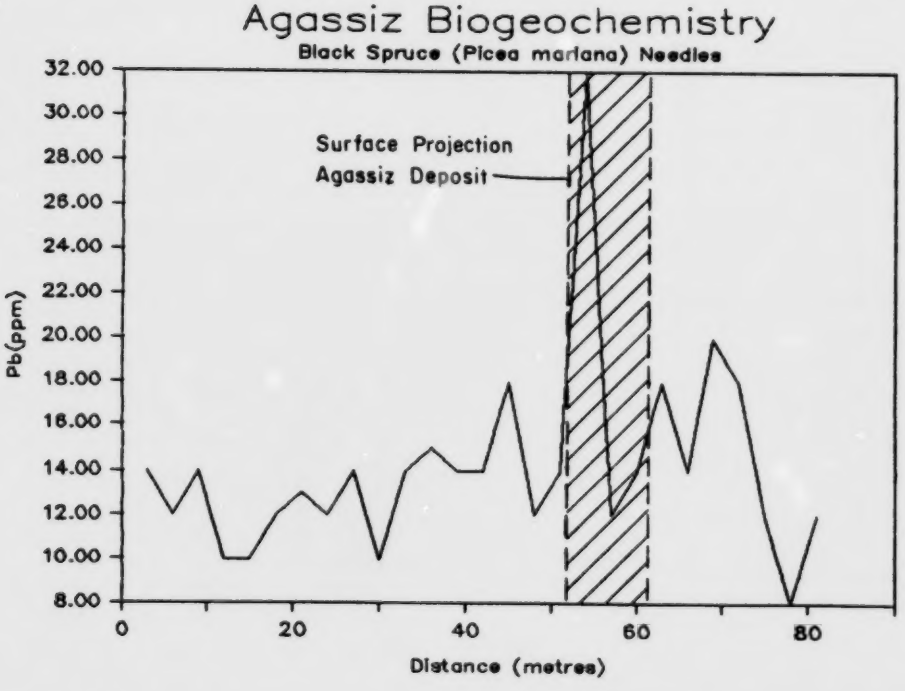
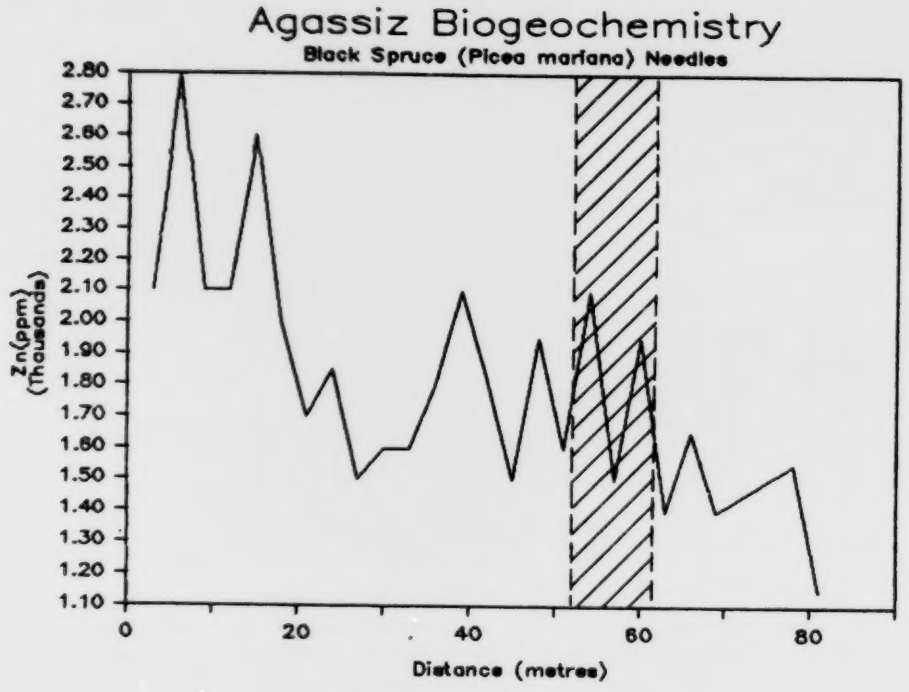


Figure 6: **Variations in concentration of Cu and Pb in ash of black spruce (Picea mariana) needles from line 6554 over the Agassiz stratabound Au-Ag deposit. Section looks west.**



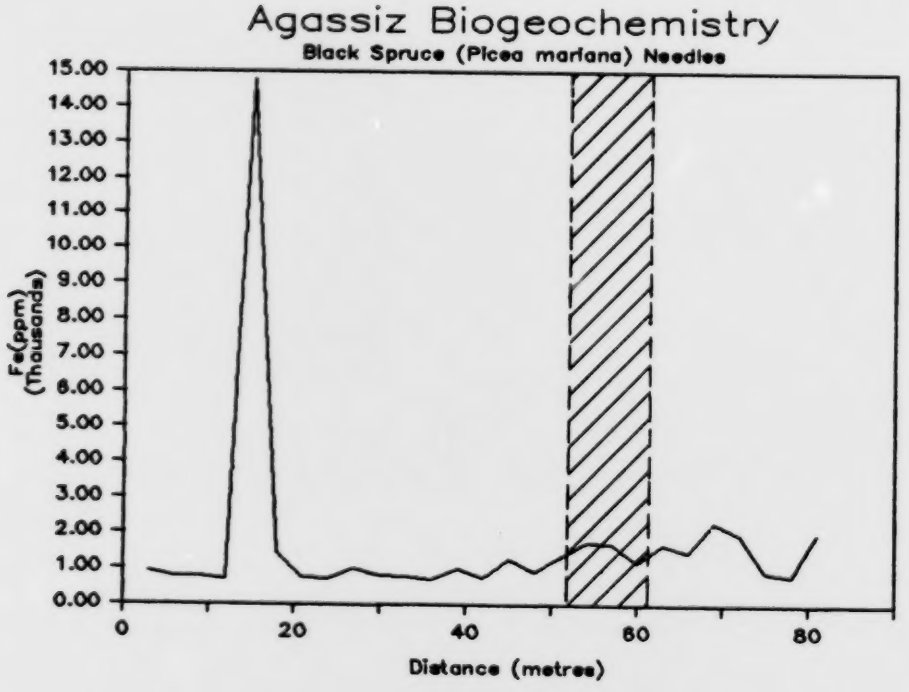
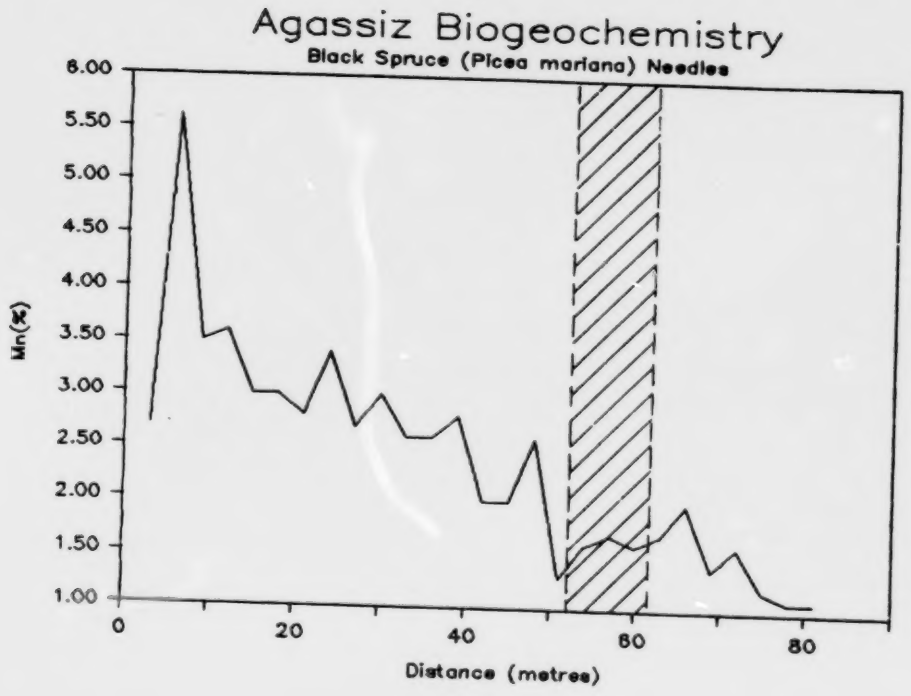


Figure 7: **Variations in concentration of Zn and Fe in ash of black spruce (Picea mariana) needles from line 6554 over the Agassiz stratabound Au-Ag deposit. Section looks west.**



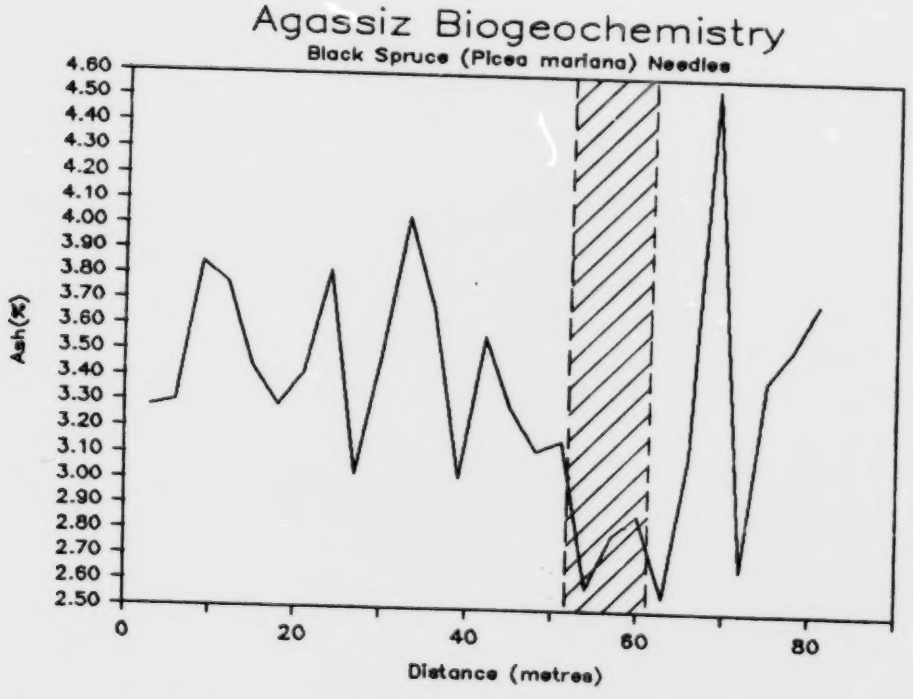


Figure 8: Variations in concentration of Mn and Ash in black spruce (Picea mariana) needles from line 6554 over the Agassiz stratabound Au-Ag deposit. Section looks west.

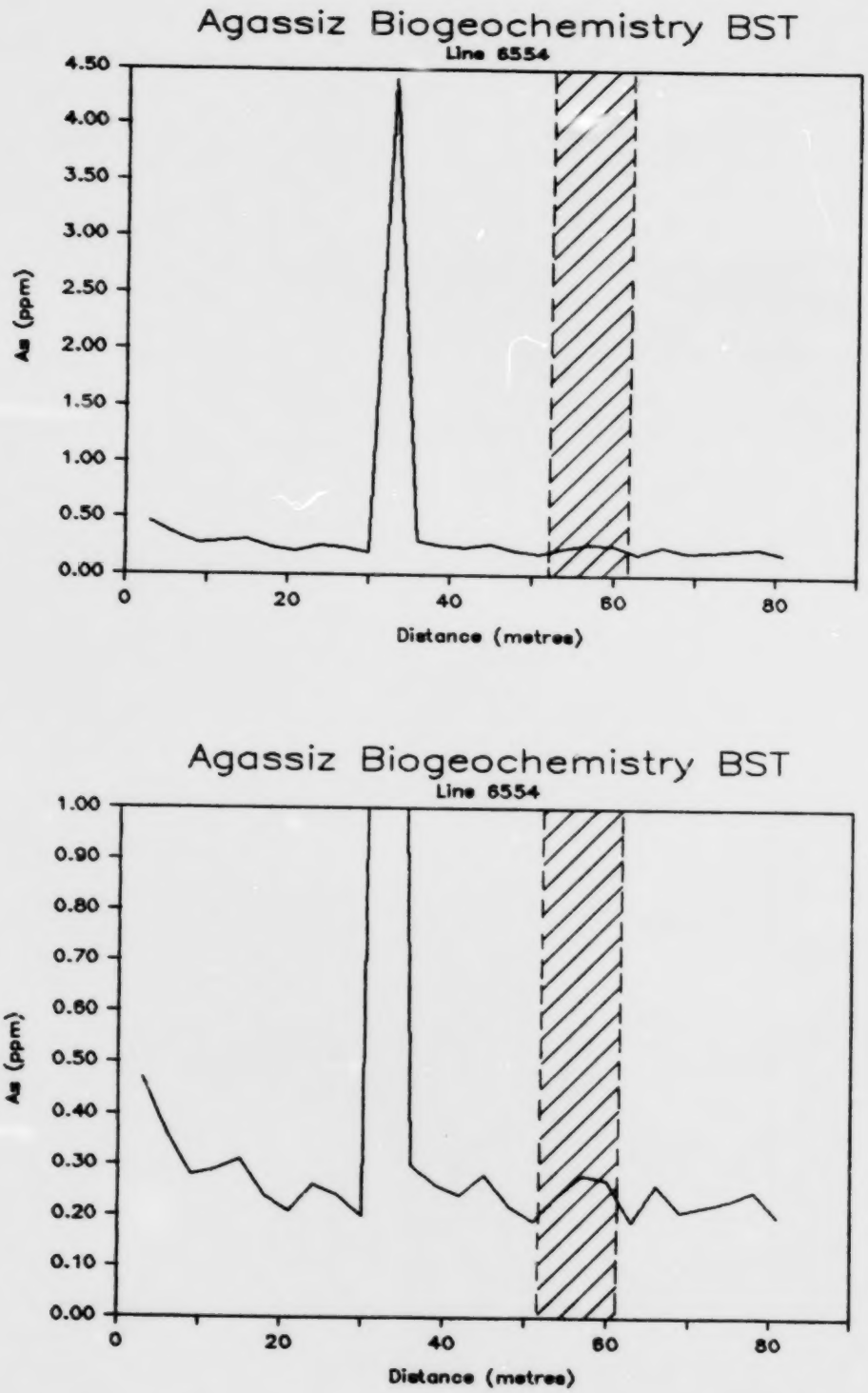


Figure 9A: Variations in concentration of As in black spruce (Picea mariana) twigs from line 6554 over the Agassiz stratabound Au-Ag deposit. Section looks west.

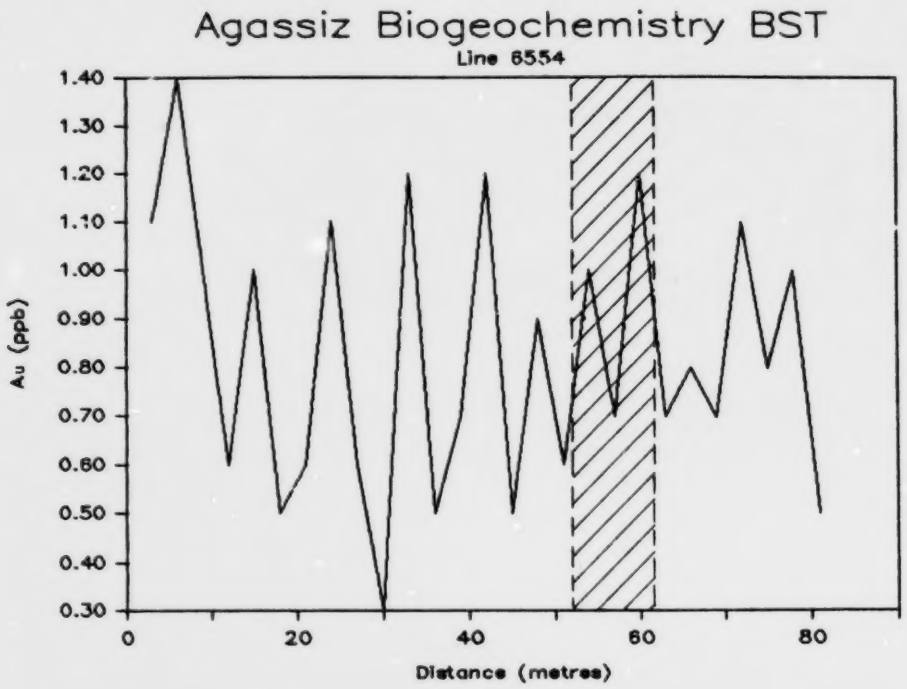
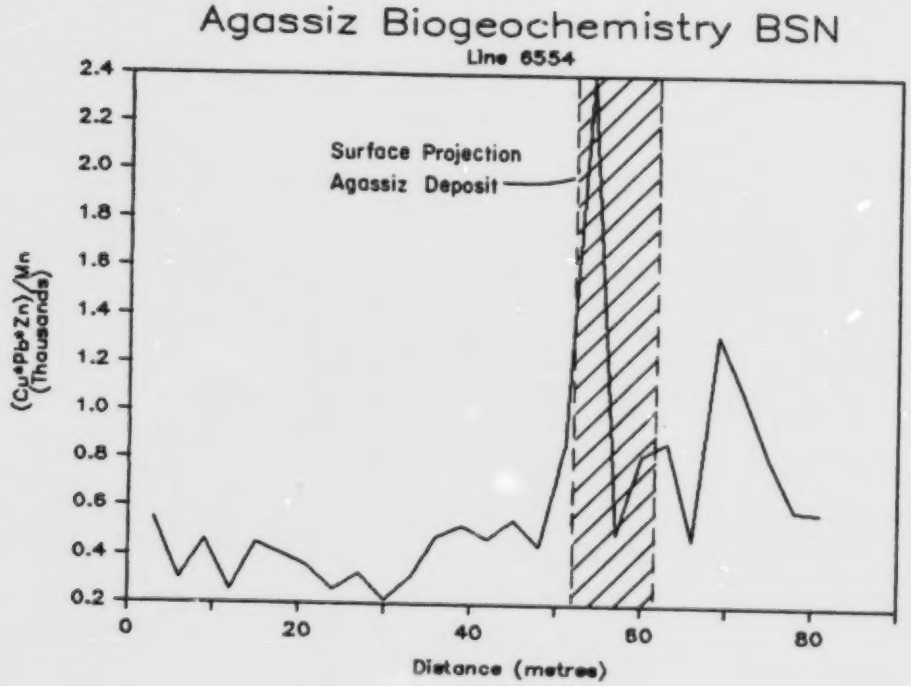


Figure 9B: Variation in concentration of Au in black spurce (Picea mariana) twigs from line 6554 over the Agassiz statabound Au-Ag deposit. Section looks west.



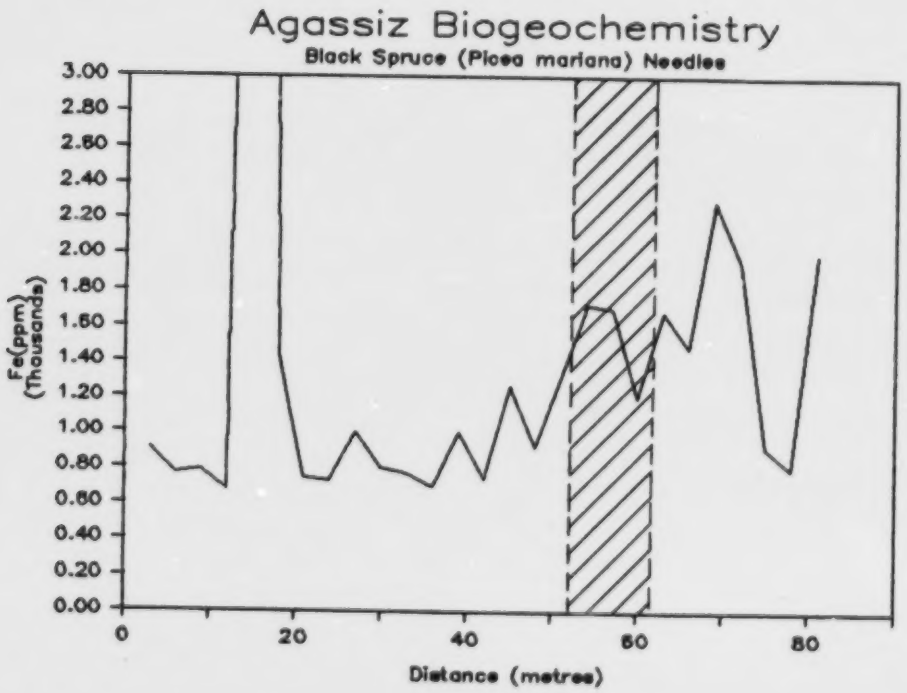


Figure 10: Variations in concentration of Fe (expanded scale) and Cu x Pb x Zn/Mn in black spruce (Picea mariana) needles from line 6554 over the Agassiz stratabound Au-Ag deposit. Section looks west.

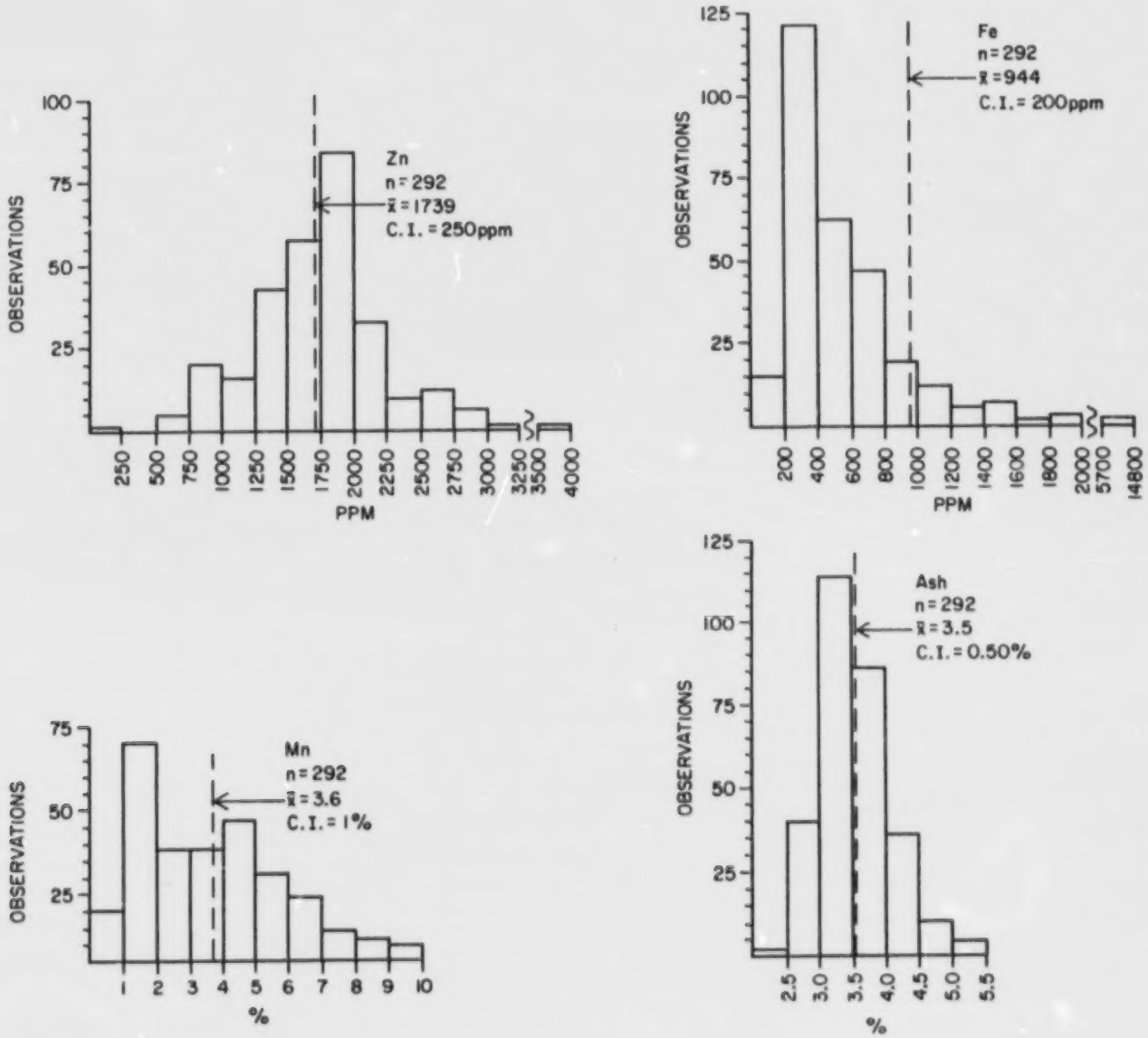


Figure 11: Histograms for Zn, Fe, Mn and Ash in black spruce (Picea mariana) needles from the Agassiz statabound Au-Ag deposit vegetation geochemical study area.

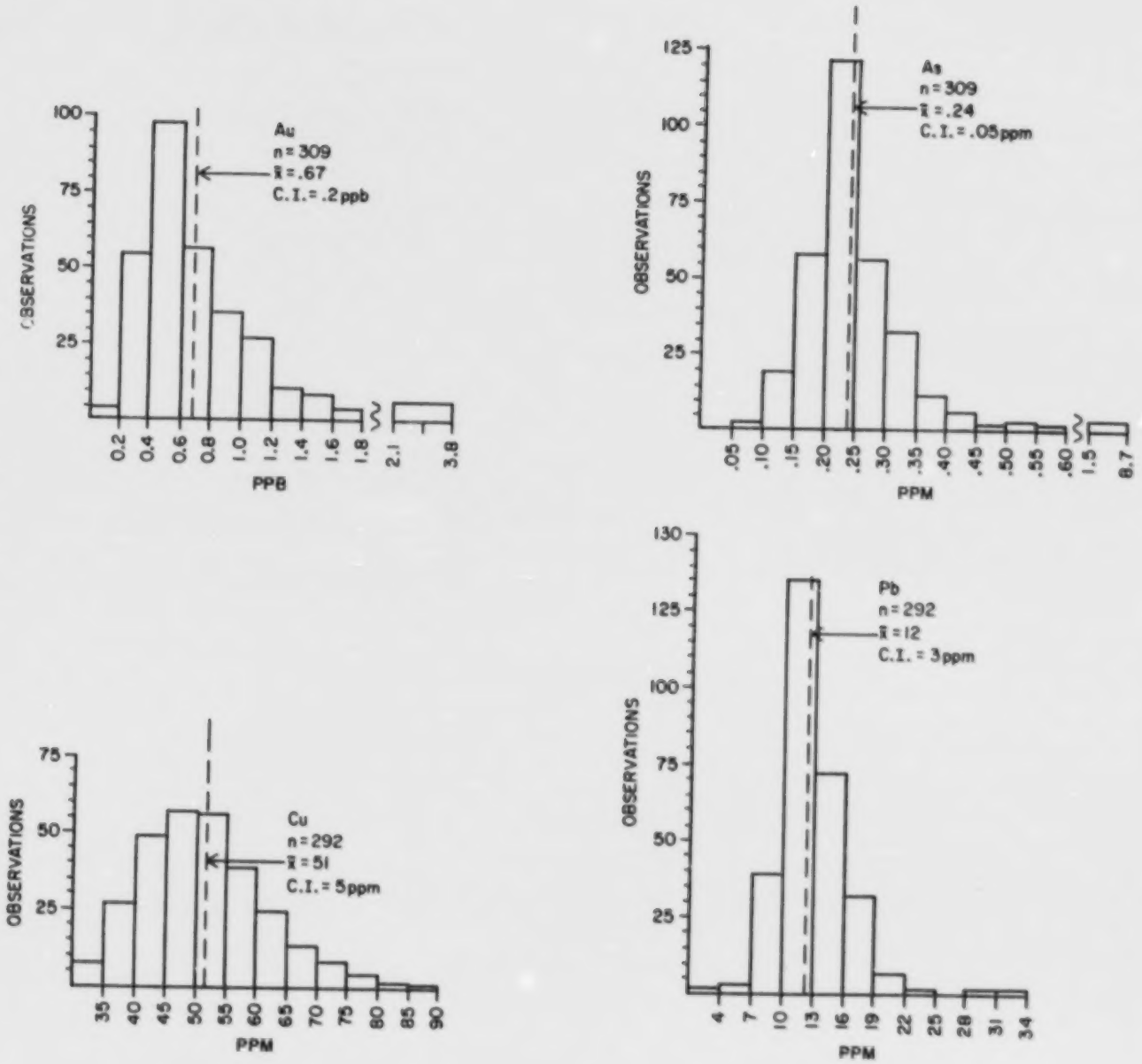


Figure 12: Histograms for Cu, Pb in black spruce (Picea mariana) needles for Au and As in black spruce twigs from the Asassiz stratabound Au-Ag deposit vegetation geochemical study area.

multiplicative and additive ratios in an attempt to more precisely define any trace element response to the subcropping Agassiz deposit. The plot for Cu x Pb x Zn/Mn successfully depicts the anomalous response of these elements with proximity to the deposit with reduced background "noise" resulting in an overall improvement in the definition and the contrast of the biogeochemical anomaly. Plots for the remainder of the trace metal ratios are presented in Appendix 3.

The results for Au and As in black spruce twigs are non-diagnostic with proximity to the Agassiz mineralization (Fig. 9A and 9B). As concentrations are restricted to 0.2 to 0.3 ppm with a single sample anomaly of 4.5 ppm downslope and displaced from the Agassiz deposit (Fig. 9A). The results for Au (Fig. 9B) are extremely erratic varying from 0.3 to 1.4 ppb.

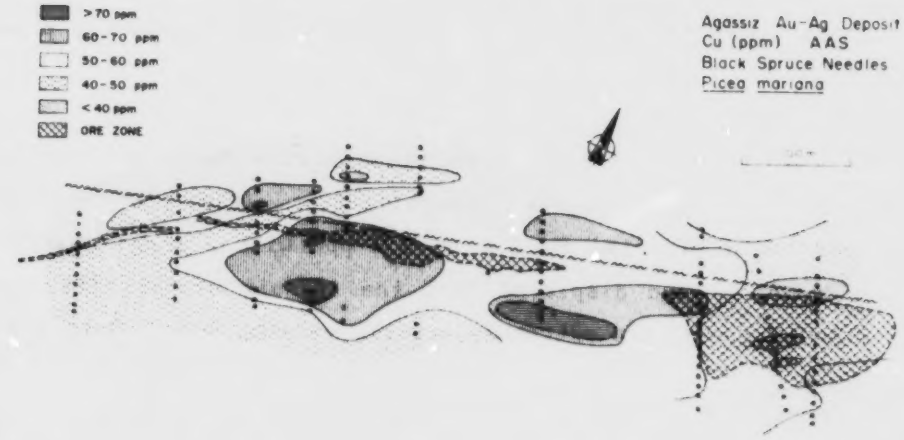
Contoured Data

Before the vegetation geochemical data was contoured the original data was reduced by averaging the analysis of a particular element for three consecutive samples and plotting the arithmetic mean at the sampling midpoint for the three samples. The data points were contoured at arbitrarily selected contour intervals (C.I.) after examination of the raw data for Cu (10 ppm), Pb (4 ppm), Zn (500 ppm), Fe (200 ppm), Mn (2%) and Ash (0.5%) in black spruce needles; in black spruce twigs As was contoured at 0.1 ppm; Au was contoured at 0.25 ppb. These results are based on 292 needle samples and 309 twig samples from 12 sampling lines over the deposit.

Black Spruce Needles

Copper (Fig. 13; C.I. = 10 ppm)

Unlike the results for Cu from line 6554, contoured Cu values indicate 2 large anomalies associated with the Central and East Zones of the deposit. The areal extent of these anomalies is 100 - 150 m x 100 m; the Cu concentrations vary from 60 - 84 ppm within these zones as compared to a



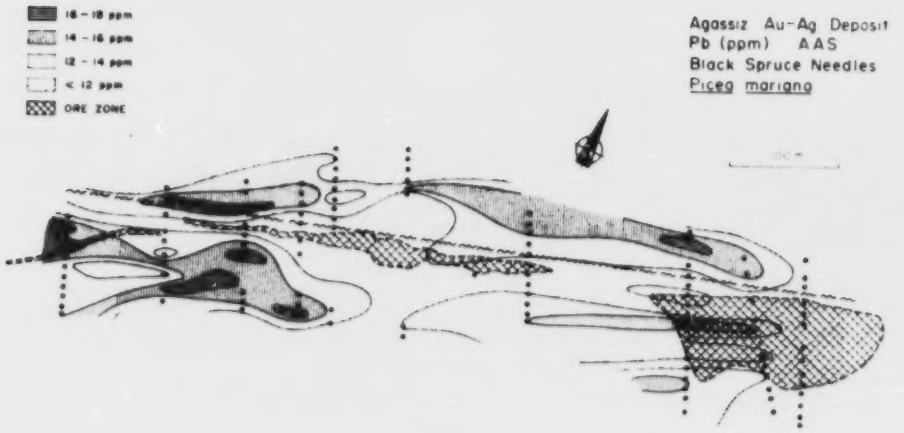


Figure 13: **Cu and Pb in black spruce (Picea mariana) needles over the Agassiz deposit. Solid circle represents the arithmetic mean of the analysis of 3 samples.**

threshold value of 51 ppm. The data distribution for Cu approximates normality but with a slight positive skew (Fig. 12). The anomalies are not centered on the mineralization but are shifted downslope or to the south of the deposit. This dislocation is directly attributable to the presence of a Cu dispersion fan in basal till which characterizes much of the substrate in which the black spruce are growing.

Two smaller, elongate, three-sample anomalies 50-100 m x 25 m are located to the north of the deposit. These features may reflect leakage halo phenomena associated with the North Shear, a structural break associated with the deposit or a second stratigraphically overlying mineralization.

Lead (Fig. 13 (b); C.I. = 4 ppm)

The distribution of Pb in black spruce needles is characterized by an absence of anomalies directly over the deposit except in the West Zone. Pb concentrations over the Central and East Zones are generally less than 12 ppm except for single sample anomalies of 14-16 ppm in a narrow anomaly (about 10 m) over the East Zone. A persistent anomaly of 14-18 ppm Pb occurs over an area of 200 m x 100 m both downslope from and directly over the Agassiz West Zone. Smaller, single-sample anomalies of 16-18 ppm are scattered throughout a larger anomaly with the range of 14-16 ppm. The Pb threshold is 17 ppm. The data distribution for Pb is similar to that for Cu with a positively skewed distribution that approximates normality (Fig. 11). In addition to the above anomalies, two significant, multi-sample Pb anomalies are located to the north of the deposit in proximity to the North Shear. These anomalies are narrow (maximum 40 m) but outline lengthy zones of 100-300 m that parallel both the strike of the host rocks to the Agassiz mineralization and to some extent that of the North Shear. The presence of a Pb dispersion fan in basal till down-ice from the deposit and the effects of leakage phenomena and/or stratigraphically overlying mineralization represent adequate explanations for the Pb vegetation anomalies.

Interpretation of the Pb anomalies is somewhat tenuous, however, owing to the overall low levels of concentration and reproducibility. The results for Pb are best interpreted in the light of the remainder of the elements in this study.

Zinc (Fig. 14 (a); C.I. = 500 ppm)

Zn results indicate broad areas of Zn concentrations in the range of 1500-2000 ppm. This broad area more or less outlines the extent of the more poorly drained substrate within the study area; however, within this 1500-2000 ppm zone there are multi-sample anomalies with greater than 2000 ppm (maximum = 9000 ppm; threshold = 1850 ppm) that are centered primarily on the East Zone and the east end of the Central Zone of the deposit. A 4 sample anomaly of greater than 2000 ppm is situated to the south of the West Zone. The data distribution for Zn closely approximates normality but with a long positively-skewed "tail" (Fig. 12). The Zn anomalies occurring over the Agassiz deposit are considered to be the reflection of stratiform, solid and disseminated sphalerite that occurs in the Agassiz deposit and the redistribution of this Zn as a dispersion fan in basal till south of the deposit. The spatially restricted high Zn zone north of the deposit (3 samples) correlates with the results for Cu and Pb.

Iron (Fig. 14 (b); C.I. = 200 ppm)

A dominant 400 m x 300 m anomaly of 1100-1300 ppm Fe in black spruce needles characterizes two-thirds of the Central Zone of the deposit. A second anomalous zone of 1100-1300 ppm occurs directly over the West Zone and extends to the south or downslope of the western one-third of the Central Zone. The areal extent of this second smaller anomaly is 200 x 75 m. Within the broad 1100-1300 m anomalies there are multi-sample anomalies of greater than 1300 ppm (maximum = 14800 ppm; Fe threshold = 1030 ppm). The Fe anomalies represent the most extensive vegetation geochemical anomaly at the deposit.

The shape of the anomaly over the Western Zone correlates with the shape of the Pb anomaly in that area. The abundance of iron sulphides in the deposit and the occurrence of other base metal dispersion fans down-ice from the deposit indicate the Fe anomalies result from a glacially derived heavy metal dispersion fan. Two smaller anomalies occur to the north of the deposit and in one case almost directly over the North Shear. The data distribution for Fe indicates a positively skewed distribution that approximates lognormality more than normality.

Manganese (Fig. 15 (a); C.I. = 2%)

The pattern of Mn concentrations in black spruce needles collected from the Agassiz study area reflects the effects of poorly drained substrate on the distribution of this element. The anomaly depicted downslope from the West and Central Zones as well as the larger Mn anomaly blanketing the East Zone can be directly related to the extent of poorly drained substrate. These anomalies depict Mn concentrations of 4-6% with a multi-sample anomaly of greater than 6% Mn (maximum = 10.0%; Mn threshold = 1.1%) outlining even poorly drained boggy substrate characterized by small pools of ponded water. The data distribution for Mn indicates a positively skewed distribution approximating lognormality (Fig. 12). It would appear that the overriding influence of drainage effects on the distribution of Mn in black spruce needles precludes an interpretation of the relationship between the Agassiz deposit and the Mn content of the needles.

Ash (Fig. 15 (b); C.I. = 0.5%)

The ash content of the needles is weakly diagnostic of proximity to mineralization in this study. Small (less than 100 m x 75 m) restricted zones of 3.5 to 4.5% ash occur directly over the deposit with 1-2 sample areas of greater than 4.5% (maximum = 5.4%; threshold = 3.9%) within these zones. Restricted, 1-2 sample anomalies of 3.5 - 4.5% ash occur south of the deposit over boggy ground where no mineralization has been discovered. The data distribution for ash approximates normality with a positive skew (Fig. 12). As in the case of Pb, the results for ash content are best interpreted with respect to the remainder of the elements in this study, although in a general sense these data suggest the occurrence of a trough of low ash contents (metal stressed vegetation?) directly over the Agassiz deposit.

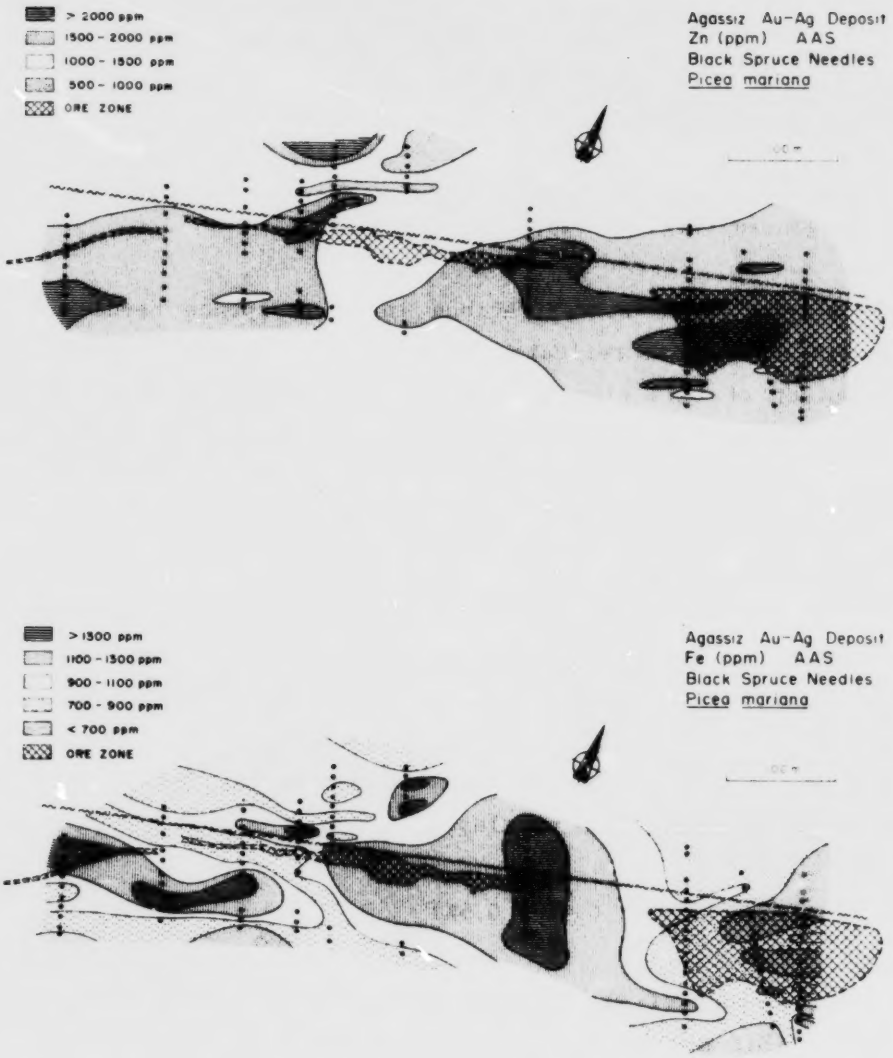
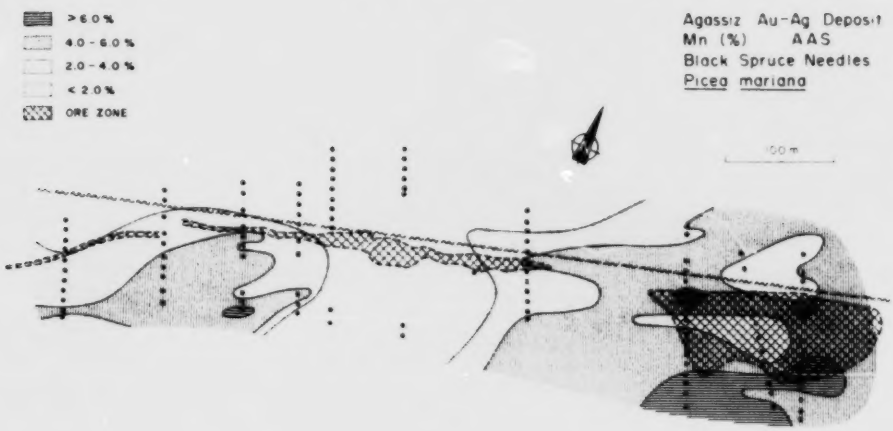


Figure 14: **Zn and Fe contents in black spruce (Picea mariana) needles over the Agassiz deposit. Solid circle represents the arithmetic mean of the analysis of 3 samples.**



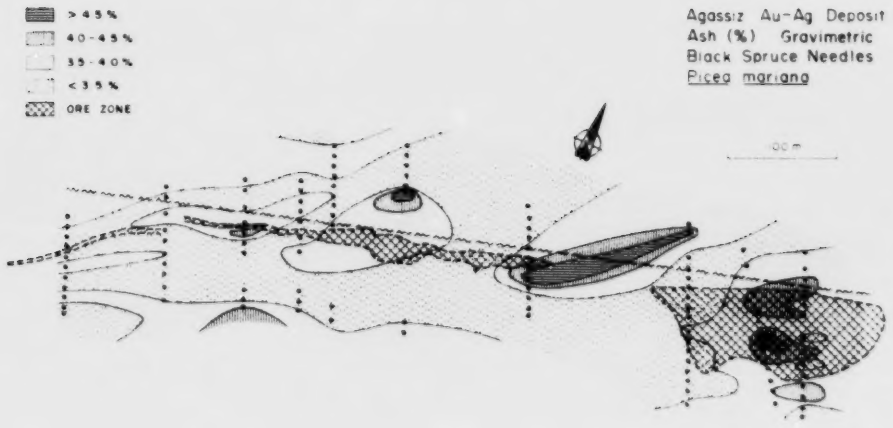
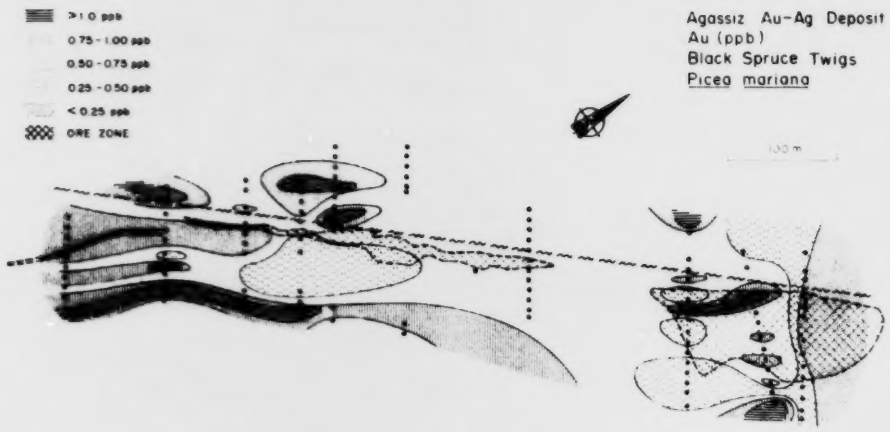


Figure 15: Mn and Ash contents in black spruce (Picea mariana) needles over the Agassiz deposit. Solid circle represents the arithmetic mean of the analysis of 3 samples.



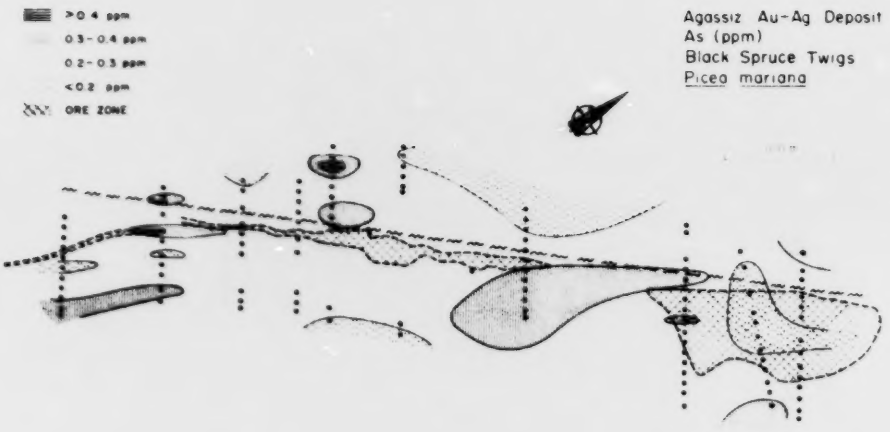


Figure 16: **Au and As in black spruce (Picea mariana) twigs over the Agassiz deposit. Solid circle represents the arithmetic mean of the analysis of 3 samples.**

Black Spruce Twigs

Gold (Fig. 16 (a); C.I. = 0.25 ppb)

The gold content of the black spruce twigs delineates scattered 1 to 4 sample anomalies of greater than 1.0 ppb over the study area. These anomalies are generally 50 m x 10 m in size with the exception of a 4 sample 250 m x 25 m anomaly that occurs downslope of the deposit in poorly drained boggy substrate. One 2-sample anomaly is associated with the deposit and this 75 m x 10 m anomaly occurs over the East Zone. Threshold for Au in the twigs is 0.5 - 0.6 ppb. The data distribution for Au is positively skewed with a long tail of anomalous Au concentrations. Gold is not considered to be a diagnostic indicator of the deposit in black spruce twigs.

Arsenic (Fig. 16 (b); C.I. = 0.1 ppm)

Contoured As values in black spruce twigs indicate a broad 250 m x 100 m multisample anomaly in the vicinity of the east end of the Central Zone and the west end of the East Zone that is shifted downslope or south of the deposit. As concentrations vary from 0.3 - 0.4 ppm within this anomaly compared to a graphically determined threshold of 0.25 ppm, the southerly extent of this anomaly correlates with the presence of an As anomaly in the clay-sized fraction (2) of basal till samples. The data distribution for As is positively skewed with a long tail of anomalous As concentrations.

A Cu, Pb, Zn, Au and As dispersion fan in basal till down ice of the deposit has been identified by Nielsen (1982, 1983) and this till, in addition to overlying humus and peat bog deposits which contain high trace metal concentrations (Table 3), characterizes the substrate for the black spruce trees. Meteoric and groundwater percolating through the substrate and reacting with the subcropping Agassiz deposit would carry dissolved metallic compounds downslope (i.e., south of the deposit) until encountering the gradually thickening organic-rich peat downslope. The metals would be "filtered" by the peat, forming organo-metallic compounds that become

available to the root systems of the black spruce in a poorly drained environment of increased trace metal availability. The metal-enriched basal till and organic-rich sediments are then tapped by the root systems of the black spruce and the progressive enrichment of the metals in the vegetation is reflected in the contoured analyses in Figures 13 (a) to 16(b). The mechanism for ion uptake by the plant occurs either as foliar absorption involving the aerial parts of the plant or as uptake at the root system. The root system acquires trace metals either through diffusion into the plant from the soil or more importantly as a result of cation exchange at the surface of clay minerals. The latter occurs when carbon dioxide (produced by respiration processes) reacts with groundwater or meteoric water and releases hydrogen ions which exchange with cations held on the clay mineral surface. As cations reach the root tip they are again replaced by hydrogen ions and the process becomes cyclical (Keller and Frederickson, 1952).

Inter-Element Associations

The examination of inter-element associations may be attempted by calculating the correlation coefficient, r, which represents a purely mathematical interpretation of the measure of the strength of a linear relationship between two variables. The value of r is devoid of any cause and effect implications. The non-parametric Kendall and Spearman correlation coefficients were calculated since the distribution of all elements is characterized by a positive skew trending to lognormality. A summary of correlation coefficients for significant element pairs in black spruce needles and twigs is presented in Table 4.

The significant positive r values for Fe-Cu, Fe-Pb, Pb-Cu and Au-As appear to be an indirect reflection of the presence of the basal till heavy metal sulphide (base metals and iron sulphides) dispersion fans. These metals in overlapping dispersion fans have been derived from the substrate by the vegetation so the high correlation between the elements in black spruce needles and twigs is not surprising. The high positive correlation between Mn and Zn reflects the increased mobility of these elements in the boggy substrate and their subsequent uptake by the black spruce [Figs. 15(a) and 14(a)].

TABLE 4

Significant Element Pairs	Spearman r	Kendall r
Fe-Cu (BSN)	0.43647	0.30676
Fe-Pb (BSN)	0.38313	0.28656
Fe-Zn (BSN)	-0.22519	-0.15465
Fe-Mn (BSN)	-0.51864	-0.20639
Fe-Ash (BSN)	-0.51864	-0.37262
Cu-Ash (BSN)	-0.53855	-0.38582
Pb-Ash (BSN)	-0.29795	-0.21717
Pb-Cu (BSN)	0.26250	0.19114
Mn-Zn (BSN)	0.40617	0.29309
Au-As (BST)	0.36052	0.26099

Table 4: Summary of correlation coefficients for significant element pairs in black spruce needles (BSN) and black spruce twigs (BST) in the Agassiz study. For BSN n = 292, BST n = 309. r at 95% confidence level for p = 0 n = 500 r = 0.074 for p = 0 n = 250 r = .104.

Significant negative correlations for Fe-Zn, Fe-Mn, Fe-Ash, Cu-Ash and Pb-Ash indicate strong inverse relationships between these variables. Negative correlations between Fe and Zn and Fe and Mn reflect the pH control of increased Zn and Mn mobility in the more poorly drained topography (Figs. 7 and 8) versus the less vigorous control of drainage over Fe (Fig. 7). Increases in ash content of black spruce needles is accompanied by decreases in the concentration of Fe, Cu and Pb as indicated by significant negative correlations for Fe, Cu and Pb with ash. As discussed in the section dealing with contoured data this correlation is apparently not rigorous enough to prevent recognition of Fe, Cu and Pb vegetation geochemical anomalies associated with the Agassiz deposit.

DISCUSSION

The migration of chemical elements in the secondary environment as related to vegetation geochemistry is controlled primarily by the regional bioclimatic factor (Malyuga, 1964). This includes the topography of the region, hydrography of the substrate, pH and Eh conditions, temperature and the presence of organic matter. Other problems in biogeochemistry have been described by Cole (1971) and these include the unpredictable rate of uptake of trace metals in specific species of plant, plant age, physiological variations within the plant and physical environmental factors. Other important factors in element migration are the chemistry of the bedrock, soil and water as well as the plants and elements involved.

In the Agassiz study the trace metal content of black spruce growing over the deposit has been affected by downslope migration of trace metals in meteoric groundwaters after percolating through the subcropping mineralization, the fixing of these metals in organic-rich soils as organo-metallic compounds, and the subsequent uptake and enrichment of these elements in black spruce growing in this substrate. In addition, the basal till portion of the substrate is characterized by well documented heavy metal dispersion fans related to the glaciation of the Agassiz deposit. In each case the substrate in which the black spruce trees were growing provides a source for the metals that define vegetation geochemical halos in this study. The correlation of trace metal concentrations between overburden and vegetation has received much attention in the literature. Dunn (1983) noted a lack of significant correlation between the U content in various organs of black spruce (**Picea mariana**), Labrador tea (**Ledum groenlandicum**), leather leaf (**Chamaedaphne calyculata**), and jack pine (**Pinus banksiana**) of northern Saskatchewan and the soils and peat in which these species were growing. Hall et al. (1973) in a comparative study of rock, soil and plant chemistry with proximity to nickel mineralization in the semi-arid and arid climate of Western Austrlia found that between soil and rock there existed a significant Ni and Cu correlation. Their studies of the correlation between the tea tree (**Melaleuca sheathiana**) and rock type indicated that no

relationship existed; however, anomalous concentrations of Ni and Cu in leaves, twigs, roots, bark and wood were observed near mineralized zones. Nicolas and Brooks (1976) studied the contents of Zn, Cu and Pb in ashed and unashed leaves and wood for two species (S. digitata and Beilschmiedia tawa) in New Zealand and indicated there existed a correlation between trace element content for vegetation and soil. In the New Zealand study no significant correlation for Cu was observed; however, significant correlations were observed for Pb in the leaves and wood of B. tawa and for Zn in leaves of S. digitata. Wolfe (1976), in a study of vegetation geochemistry near porphyry-style Mo-Cu mineralization at Setting Net Lake, Kenora, reports that a pattern of anomalously high Mo in second year black spruce needles growing in swamp and clay environments not only reflects mineralization but the anomaly is more sharply defined than the corresponding soil anomaly. Steed et al. (1976), in a study of biogeochemical prospecting near the Ogofau gold mines, Wales, conclude that two-year-old birch twigs produced the greatest anomaly contrast and magnitude and that anomalies detected for most elements (Pb, Zn, Rb, Mn, Cu, Ni and Fe) were comparable to soil anomalies for the same elements. Leavitt and Goodell (1979) evaluated vegetation geochemical prospecting for sulphide mineralization in Virginia and indicate that although plant Pb contents were unresponsive to soil Pb contents there exists a strong correlation between Zn and Cd in mature oak leaves and twigs of the current year's growth and the content of these metals in the soil thereby reliably reflecting mineralization.

The results of the Agassiz study are sympathetic with those of the studies suggesting significant correlations do exist between trace element concentrations in vegetation and the underlying substrate. The trace metal contents of both black spruce needles and twigs growing over the Agassiz deposit are reliable indicators of anomalous concentrations of the same trace metals in the substrate. The substrate, characterized to a large degree by till, contains heavy metal dispersion fans derived from the glaciation of the Agassiz deposit.

The possible need to standardize trace element data with respect to changing drainage characteristics has been discussed in OF84-1 and although no standardization for pH was undertaken for the Agassiz study trace metals were ratioed against Mn in an attempt to derive maximum anomaly contrast for the data. The variations in the physico-chemical nature of the substrate in the Agassiz study area, i.e., well drained sandy till and humus to wet permafrost peat bog and the associated pH changes, require some considerations as to the effects of these changes on the availability of trace metals between a well drained and poorly drained substrate. The changes in the mobility of trace metals due to changing pH has been addressed in the literature, particularly by workers in the agricultural sciences. Iu et al. (1982) detailed the influence of soil waterlogging on plant growth and trace metal content. This study examined the uptake of trace metals by the French bean (Phaseolus vulgaris) and by Maize (Zea mays). They found the uptake of Mn, Fe and Co was increased due to soil waterlogging; the French bean showed preferential uptake of Zn whereas Maize incorporated Cu more readily in waterlogged soil. Additional studies by workers in the agricultural sciences indicate that soil waterlogging results in the partitioning of Fe, Mn, Zn and Cu among various mineral species in the substrate with the result that the availability of Fe and Mn to the plant would be increased and Zn and Cu would be decreased. Overall, the behaviour of Zn and Cu in soils under waterlogged or ponded conditions is complex with reports of the availability of trace metals in the soil decreasing (Haldar and Mandal, 1979; International Rice Institute, 1977; Iu et al., 1981) and increasing (Mitchell et al., 1975; Mitchell, 1964; Ng and Bloomfield, 1952). Ignatieff (1952) concludes that the availability of Zn and Cu for plant nutrition in the soil is greatest in the range pH 4.5 - 6.0. This author summarizes the effect of pH on the availability of trace metals in soils to plants. Wolfe (1976) confirmed pH-solubility relationships suggesting increased solubility, i.e., mobility of the molybdate $(MoO_4)^{2-}$ ion, with increasing pH. In a geological sense, Timperley et al. (1970a) examined the pH dependence of metal uptake by New Zealand plants. In this study enrichment coefficients for Cu, Ni and Zn for 300 samples of four species were correlated statistically with the pH values of the soils in which the species were growing. The only element for which a significant correlation between enrichment coefficient and soil pH (indicating a pH dependence of metal uptake) in each of the four species was Ni. The

study found that nickel accumulation decreased as the pH was raised. The control of drainage and pH on trace element availability therefore becomes apparent in any local or regional scale vegetation geochemical survey, i.e., standardization of topography during sample collection should be considered where drastic changes in the drainage regimes are present. Clearly, the ratio of Cu x Pb x Zn/Mn for Agassiz black spruce needles outlines the deposit and is certainly "quieter" with less erratic peaks and troughs of varying concentrations than any single element profile. Brooks (1972) summarizes previous studies (Brooks and Lyon. 1966; Lyon and Brooks, 1969) indicating that provided the pH range is not drastic in the study area the vegetation geochemical technique for prospecting is valid.

Although significant correlations exist for Fe, Cu and Pb with ash in the black spruce needles collected over the Agassiz deposit the extent of both the Cu and Fe vegetation geochemical anomalies would seem to negate the need for standardizing trace elements to a fixed ash content in this study. The anomalies, particularly in the case of Fe, occur within well drained as well as poorly drained substrate. Other work related to gold mineralization detail similar results with respect to this problem. Steed et al. (1976) conclude that the conversion of trace element concentrations to dry twig weight, i.e., normalizing with respect to ash content, did not significantly alter the size and location of vegetation geochemical anomalies associated with auriferous vein-type mineralization. These authors also concluded, on the basis of their orientation survey, that the age of the twigs (sampled from shoulder height around the perimeter of the birch trees in the study area) had little effect on metal concentrations with the exception that Pb was significantly higher in second-year twigs versus first-year twigs. These results would tend to corroborate the sampling method of bulking 1-7 years' growth of black spruce needles and twigs utilized for the Agassiz study. Although concentration differences have been documented in different ages of specific plant organs (Brooks, 1972) these differences are apparently not great enough to mask the trace metal contribution in the plant from the source anomaly in the substrate.

The study by Steed et al. (1976) discusses the advantages to using vegetation geochemical surveys over soil geochemical surveys. They indicate vegetation is capable of concentrating metals from a wider area and vegetation

is much easier to sample and to prepare for analysis. In addition the ashing of the materials effectively concentrates the element being sought (80 times concentration factor for Pb, Zn, Rb, Mn, Cu, Ni and Fe in birch leaves and twigs; 40 times for oak) and thereby simplifies the analysis, i.e., there is less concern for low limits of detection and problems of sample inhomogeneity. As evidence for the selection of vegetation over rock geochemistry the authors indicate that two strong vegetation geochemical anomalies defined over the southern part of the Ogofau ore zone (Pb in birch twig ash) were absent in a rock geochemical survey. This was due to the fact that the roots of the birch were able to penetrate fissures developed by the decomposition of gold- and sulphide-bearing quartz veins subsequently transporting the associated Pb upwards into the trees. No Pb halo effect was observed in the rock geochemical survey probably because dispersion halos adjacent to vein-type mineralization are characteristically narrow; the rock sampling interval was apparently too wide.

CONCLUSIONS

The following conclusions are evident from this vegetation geochemical survey of the Agassiz stratabound Au-Ag deposit.

1. Black spruce (Picea mariana) represents a viable sampling medium for vegetation geochemical surveys designed to locate Agassiz-type mineralization in glaciated terrain where gold is associated with arsenopyrite, sphalerite, galena and abundant iron sulphides.

2. Analysis of black spruce samples can be conducted using AAS and INAA; reproducibility for AAS analyses is excellent; INAA reproducibility is acceptable.

3. Black spruce needles and twigs must be analyzed separately for specific indicator elements which should be determined in an orientation survey.

4. The trace element content of the black spruce reasonably approximates that of the underlying substrate. In the Agassiz study the vegetation reflects the presence of base and precious metal dispersion fans delineated in basal till samples. As in the Agassiz study it may become necessary to examine data from more than one sampling line to properly evaluate this method.

5. Standardizing trace metal concentrations with respect to ash content was unnecessary; the geochemical signature of the vegetation is unaffected by the range of ash contents encountered in this study.

6. The effects of pH and subsequent element mobility and uptake by vegetation should be addressed by standardizing topography where samples are collected (i.e., avoiding ponded waters). If this procedure is not possible then utilizing ratioed data, for instance Cu x Pb x Zn/Mn, to help compensate for enhanced element mobility owing to poorly drained portions of the study area should be undertaken.

7. The biogeochemical anomalies defined by this study represent an exploration target larger than the mineralization and as such the vegetation geochemical survey method can be used to focus conventional exploration techniques into much reduced target areas.

8. Samples of black spruce needles and twigs can be collected at 100 m sampling intervals utilizing a 10 m^2 box at each sampling site in the search for Agassiz-type mineralization. Needles and twigs must be collected from the north, south, east and west sides of each tree within the sampling box.

9. This type of geochemical survey represents a viable technique for application to gold exploration within the Agassiz Metallotect. If conducted properly the method is simpler, faster and more cost-effective than either basal till or rock geochemistry.

ACKNOWLEDGEMENTS

Rob Charlesworth and Cliff Duke are sincerely thanked for their efforts in sampling black spruce trees over the Agassiz deposit and for their perseverence in sample preparation. Simon Wilkins is thanked for the floral speciation (Table 1) in the bog and boreal forest environments in the vicinity of the Agassiz deposit. Sherritt Gordon Mines Ltd. are acknowledged for their permission for access to the Agassiz deposit. Ron DiLabio, Geological Survey of Canada, is thanked for his assistance in the early stages of this program and ongoing discussions. The Word Processing Centre is thanked for typing this report.

REFERENCES

Bateman, J.D.
1945: McVeigh Lake area, Manitoba; Geological Survey of Canada Paper 45-14.

Brooks, R.R. and Lyon, G.L.
1966: Biogeochemical prospecting for molybdenum in New Zealand; New Zealand Journal of Science, v. 9, p. 706-718.

Brooks, R.R.
1972: Geobotany and biogeochemistry in mineral exploration; Harper and Row, New York.

Cohen, D.R., Hoffman, E.L. and Nichol, I.
1985: Biogeochemistry: a geochemical method for gold exploration in the Canadian Shield; in: 11th International Geochemical Exploration Symposium, Toronto, Program and Abstracts, p. 47.

Cole, M.M.
1971: The importance of environment in biogeographical/geobotanical and biogeochemical investigations; Canadian Institute of Mining and Metallurgy, Special Volume 11, p. 414-425.

Dunn, C.E.
1981: The biogeochemical expression of deeply buried uranium mineralization in Saskatchewan, Canada; Journal of Geochemical Exploration, v. 15, p. 437-452.

Fedikow, M.A.F
1984: Preliminary results of biogeochemical studies in the Lynn Lake Area; in: Manitoba Mineral Resources Division Open File Report OF84-1, 104 p.

Gilbert, H.P., Syme, E.C. and Swanzig, H.V.
1980: Geology of the metavolcanic and volcaniclastic metasedimentary rocks in the Lynn Lake area; Manitoba Mineral Resources Division Geological Paper GP80-1.

Guha, M.
1961: A study of the trace element uptake of deciduous trees; Ph.D. thesis, University of Aberdeen (quoted in Brooks, 1972, p. 104).

Haldar, M. and Mandal, L.N.
1979: Influence of soil moisture regimes and organic matter application on the extractable Zn and Cu content in rice soils; Plant and Soil, 53, p. 203-213.

Hall, J.S., Both, R.A. and Smith, F.A.
1973: A comparative study of rock, soil and plant chemistry in relation to nickel mineralization in the Pioneer area, Western Australia; Proceedings of the Australasian Institute of Mining and Metallurgy, no. 247, p. 11-22.

Hawkes, H.E. and Webb, J.S.
1962: Geochemistry in mineral exploration; Harper and Row, New York.

Ignatieff, V.
1952: Efficient use of fertilizers; p. 7; Leonard Hill Publishers, London.

International Rice Research Institute
1977: Annual Report 1976; The International Rice Reseach Institute, Los Banos, Phillipines.

Iu, K.L., Pulford, I.D. and Duncan, H.J.
1981: Influence of waterlogging and lime or organic-matter additions on the distribution of trace metals in an acid soil; Part I: Manganese and iron; Part II: Zinc and copper; Plant and Soil, 59(2), p. 317-333.

1982: Influence of soil waterlogging on subsequent plant growth and trace metal content; Plant and Soil, v. 66, p. 423-427.

Keller, W.D. and Frederickson, A.F.
1952: Role of plants and colloidal acids in the mechanism of weathering; American Journal of Science, v. 250, p. 594-608.

Leavitt, S.W. and Goodell, H.G.
1979: Evaluation of biogeochemical prospecting methods in the search for sulphide deposits in the Appalachian Piedmont, Virginia, U.S.A.; Journal of Geochemical Exploration, v. 11, p. 89-100.

Lyon, G.L. and Brooks, R.R.
1969: The trace element content of Olearia rani and its application to biogeochemical prospecting; New Zealand Journal of Science, v. 12, p. 200-206.

Malyuga, D.P.
1964: Biogeochemical methods of prospecting; Consultants Bureau Translation, New York.

Mitchell, R.L., Reith, J.W.S. and Johnson, I.M.
1957: Trace-element uptake in relation to soil content; Journal of the Science of Food and Agriculture, 8, S51-S59.

Mitchell, R.L.
1964: Trace elements in soils - chapter 8; in: Chemistry of the soil (ed. F.E. Bear), Van Nostrand Reinhold Co., New York, p. 320-368.

Nicholas, D.J. and Brooks, R.R.
1969: Biogeochemical prospecting for zinc and lead in the Te Aroha region of New Zealand; Proceedings of the Australian Institute of Mining and Metallurgy, no. 231, p. 59-66.

Nielsen, E.
1982: Overburden sampling in the Lynn Lake area; in: Manitoba Mineral Resources Division, Report of Field Activities 1982, p. 81-83.

1983: Overburden sampling in the Lynn Lake area; in: Manitoba Mineral Resources Division, Report of Field Activities 1983, p. 98-100.

Ng, S.R. and Bloomfield, C.
1962: The effect of flooding and aeration on the mobility of certain trace elements in soils; Plant and Soil, 16, p. 108-135.

Shacklette, H.T.
1960: Soil and plant sampling at the Mahoney Creek lead-zinc deposit, Revillagigedo Island, SE Alaska; United States Geological Survey Professional Paper 400-B, p. 102-104.

Stednick, J.D., Klem, R.B. and Riese, W.C.
1985: Temporal variation of metal concentrations in biogeochemical samples over a mineralized complex in the Breckenridge Mining District, Summit County, Colorado, U.S.A.; in: 11th International Geochemical Exploration Symposium, Toronto, Program and Abstracts, p. 87-88.

Steed, G.M., Annels, A.E., Shrestha, P.L. and Tater, P.S.
1976: Geochemical and biogeochemical prospecting in the area of the Ogofau gold mine, Dyfed, Wales; Institution of Mining and Metallurgy Transactions, v. 85(2), p. B109-B117.

Tennant, C.B. and White, M.L.
1959: Studies of the distribution of some geochemical data; Economic Geology, v. 54, p. 1281-1290.

Wolfe, W.J.
1976: Geochemical and biogeochemical exploration of molybdenum-copper mineralization at Setting Net Lake, District of Kenora (Patricia Portion); Geoscience Report 156, Ontario Division of Mines, 28 p.

APPENDIX 1

Raw Analytical Data and Duplicate Sample Reproducibility

Agassiz Biogeochemistry
Black Spruce (Picea mariana) Needles Zn. As, Sb (ppm); Au (ppb) (INAA) (Dry Sample)
Raw Data and Duplicate Reproducibility
Orientation Survey

SAMPLE	Zn (ppm)	As (ppm)	Sb (ppm)	Au (ppb)
AGB-0	21	0.11	0.01	0.5
AGB-1	23	0.10	0.01	0.3
AGB-6	24	0.10	0.01	0.7
AGB-8	40	0.10	nd	0.5
AGB-9	30	0.28	0.01	0.4
AGB-10	25	0.16	nd	0.4
AGB-11	23	0.30	0.01	0.5
AGB-12	32	0.51	nd	0.1
AGB-13	36	0.31	0.01	0.8
AGB-14	33	0.23	nd	0.3
AGB-15	32	0.13	nd	0.4
AGB-18	35	0.06	nd	0.3
AGB-19	34	0.10	nd	0.4
AGB-20	33	0.10	nd	0.6
AGB-21	37	0.07	0.01	0.5
AGB-22	30	0.07	nd	0.6
AGB-23	25	0.06	0.01	0.3
AGB-24	30	0.08	nd	0.8
AGB-25	31	0.07	0.01	0.4
AGB-26	29	0.12	nd	0.6
AGB-27	22	0.10	nd	0.4
AGB-28	28	0.06	nd	0.5
AGB-29	20	0.05	nd	0.4
AGB-30	29	0.07	nd	0.5
AGB-203	72	0.14	0.01	0.5
AGB-204	72	0.14	0.01	0.5
AGB-205	59	0.09	0.01	0.6
AGB-207	65	0.12	0.02	0.7
AGB-208	69 (57)	0.10 (0.11)	0.01 (0.01)	1.1 (0.4)
AGB-209	67	0.10	nd	0.6
AGB-212	52	0.08	0.01	0.6
AGB-213	67	0.10	0.01	0.6
AGB-214	38	0.09	0.01	1.1
AGB-215	40	0.09	0.01	0.6
AGB-216	36 (32)	0.06 (0.04)	0.01 (0.01)	0.4 (0.4)
AGB-217	28	0.08	nd	0.5
AGB-218	39	0.07	nd	0.5
AGB-219	39	0.09	nd	0.6
AGB-220	31	0.06	nd	0.5
AGB-221	32	0.09	nd	1.0
AGB-224	28 (28)	0.08 (0.06)	0.01 (0.01)	0.6 (0.5)
AGB-225	23	0.06	nd	0.5
AGB-226	22	0.05	0.01	0.4

NOTE: Bracketed figure represents the duplicate analysis.

Agassiz Biogeochemistry
Black Spruce (Picea mariana) Needles Zn, As, Sb (ppm); Au (ppb) by (INAA)
Orientation Survey

SAMPLE	Zn (ppm)	As (ppm)	Sb (ppm)	Au (ppb)
AGB-0	21	0.11	0.01	0.5
AGB-1	23	0.10	0.01	0.3
AGB-6	24	0.10	0.01	0.7
AGB-8	40	0.10	nd	0.5
AGB-9	30	0.28	0.01	0.4
AGB-10	35	0.16	nd	0.4
AGB-11	23	0.30	0.01	0.5
AGB-12	32	0.51	nd	0.1
AGB-13	36	0.23	nd	0.3
AGB-14	33	0.23	nd	0.3
AGB-15	32	0.23	nd	0.3
AGB-18	35	0.06	nd	0.3
AGB-19	34	0.10	nd	0.4
AGB-20	33	0.10	nd	0.6
AGB-21	37	0.07	0.01	0.5
AGB-22	30	0.07	nd	0.6
AGB-23	25	0.06	0.01	0.3
AGB-24	30	0.08	nd	0.8
AGB-25	31	0.07	0.01	0.4
AGB-26	29	0.12	nd	0.6
AGB-27	22	0.10	nd	0.4
AGB-28	28	0.06	nd	0.5
AGB-29	20	0.05	nd	0.5
AGB-30	29	0.07	nd	0.5
AGB-203	72	0.14	0.01	0.5
AGB-204	72	0.14	0.01	0.5
AGB-205	59	0.08	0.01	0.6
AGB-207	65	0.12	0.02	0.7
AGB-208	63	0.11	0.01	0.8
AGB-209	67	0.10	nd	0.6
AGB-212	52	0.08	0.01	0.6
AGB-213	67	0.10	0.01	0.6
AGB-214	38	0.09	0.01	1.1
AGB-215	40	0.09	0.01	0.6
AGB-216	34	0.05	0.01	0.4
AGB-217	28	0.08	nd	0.5
AGB-218	39	0.07	nd	0.5
AGB-219	39	0.09	nd	0.6
AGB-220	31	0.06	nd	0.5
AGB-221	32	0.09	nd	0.8
AGB-224	28	0.07	0.01	0.5
AGB-225	23	0.06	nd	0.5
AGB-226	22	0.05	0.01	0.4

Agassiz Biogeochemistry
Black Spruce (Picea mariana) Twigs; Zn, As, Sb (ppm); Au (ppb) by (INAA) (Dry Sample)
Orientation Survey

SAMPLE	Zn (ppm)	As (ppm)	Sb (ppm)	Au (ppb)
AGB-0	44	0.29	0.04	1.3
AGB-1	42	0.23	0.10	0.6
AGB-6	44	0.22	0.03	0.7
AGB-8	44	0.23	0.03	1.2
AGB-9	44	0.36	0.09	2.4
AGB-10	48	0.27	0.04	0.8
AGB-11	49	0.24	0.03	0.4
AGB-12	48	0.25	0.07	0.8
AGB-13	45	0.21	0.02	1.2
AGB-14	39	0.15	0.35	0.6
AGB-15	43	0.15	0.03	1.0
AGB-18	40	0.15	0.02	1.7
AGB-19	50	0.25	0.07	1.7
AGB-20	38	0.20	0.03	1.1
AGB-21	38	0.21	0.02	0.4
AGB-22	32	0.14	0.02	0.4
AGB-23	35	0.16	0.02	0.4
AGB-24	32	0.17	0.03	0.8
AGB-25	43	0.16	0.06	0.8
AGB-26	34	0.16	0.03	1.6
AGB-27	31	0.13	0.12	1.4
AGB-28	29	0.14	0.04	0.6
AGB-29	30	0.16	0.02	1.8
AGB-30	27	0.14	0.03	0.7
AGB-203	45	0.35	0.03	0.5
AGB-204	53	0.23	0.02	0.4
AGB-205	47	0.26	0.02	0.6
AGB-207	44	0.22	0.02	0.5
AGB-208	49	0.23	0.02	0.5
AGB-209	37	0.20	0.01	0.7
AGB-212	31	0.08	0.01	0.2
AGB-213	37	0.17	0.01	0.3
AGB-214	31	0.13	0.01	0.3
AGB-215	30	0.13	0.01	0.1
AGB-216	32	0.17	0.01	0.3
AGB-217	29	0.11	0.01	0.4
AGB-218	34	0.15	0.01	0.2
AGB-219	32	0.12	0.01	0.4
AGB-220	26	0.15	0.01	0.4
AGB-221	27	0.19	0.01	0.3
AGB-224	36	0.19	0.02	0.4
AGB-225	36	0.21	0.02	0.4
AGB-226	31	0.21	0.02	0.4

Agassiz Biogeochemistry - Raw Data
Black Spruce (Picea mariana) Needles Cu, Pb, Zn, Fe (ppm), Mn (%) by Atomic Absorption
Ash (%) - Gravimetric

SAMPLE	Cu (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	Mn (%)	Ash (%)
AGB-31	48	14	2100	910	2.7	3.28
AGB-33	50	12	2800	770	5.6	3.30
AGB-35	55	14	2100	790	3.5	3.85
AGB-36	44	10	2100	680	3.6	3.77
AGB-38	52	10	2600	14800	3.0	3.44
AGB-39	51	12	2000	1440	3.0	3.29
AGB-40	45	13	1700	750	2.8	3.42
AGB-41	40	12	1850	730	3.4	3.82
AGB-43	42	14	1500	1000	2.7	3.03
AGB-44	41	10	1600	800	3.0	3.49
AGB-45	36	14	1600	770	2.6	4.04
AGB-46	46	15	1800	700	2.6	3.68
AGB-47	50	14	2100	1000	2.8	3.02
AGB-48	37	14	1820	740	2.0	3.57
AGB-49	44	18	1500	1260	2.0	3.29
AGB-50	49	12	1950	920	2.6	3.13
AGB-51	50	14	1600	1320	1.3	3.17
AGB-52	57	32	2100	1720	1.6	2.59
AGB-53	47	12	1500	1700	1.7	2.80
AGB-54	48	14	1950	1200	1.6	2.88
AGB-55	59	18	1400	1680	1.7	2.56
AGB-56	41	14	1650	1480	2.0	3.12
AGB-57	66	20	1400	2300	1.4	4.56
AGB-58	66	18	1450	1960	1.6	2.67
AGB-59	54	12	1500	920	1.2	3.41
AGB-60	53	8	1 50	800	1.1	3.54
AGB-61	47	12	1150	2000	1.1	3.72
AGB-62	39	12	1600	650	4.2	3.53
AGB-63	40	12	1650	670	5.8	3.86
AGB-64	56	14	2050	800	4.5	3.02
AGB-65	49	18	1750	1380	4.6	3.30
AGB-66	46	16	1600	920	4.5	3.24
AGB-67	50	14	1900	1860	6.0	2.87
AGB-68	51	12	1900	1820	6.0	2.69
AGB-69	44	10	1950	1440	5.6	3.35
AGB-70	52	12	1900	1360	5.5	3.60
AGB-71	56	14	1900	960	5.7	3.03
AGB-72	58	14	2000	1280	4.4	2.09
AGB-73	54	16	1788	990	4.6	3.21
AGB-74	45	12	2150	820	6.4	3.64
AGB-75	58	10	1600	1600	4.3	2.77
AGB-76	41	12	1800	730	4.4	4.06
AGB-77	46	14	1650	1140	3.2	3.54
AGB-78	50	12	2000	800	2.7	3.30

SAMPLE	Cu (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	Mn (%)	Ash (%)
AGB-79	46	14	1900	1280	3.7	3.45
AGB-80	52	12	1300	1080	4.0	2.77
AGB-81	56	14	1900	750	4.0	3.65
AGB-82	47	10	1825	900	3.5	3.28
AGB-83	43	12	1675	725	2.3	3.83
AGB-84	41	16	1650	760	2.0	3.61
AGB-85	56	14	1250	1000	1.4	2.50
AGB-86	50	18	800	1220	1.4	3.43
AGB-87	48	12	1000	810	1.3	3.64
AGB-88	57	10	950	1000	1.4	3.94
AGB-89	47	12	1100	800	1.2	4.06
AGB-90	46	12	1525	660	6.1	4.04
AGB-91	48	18	1600	820	6.4	3.87
AGB-92	45	12	1450	1000	5.1	3.33
AGB-93	58	16	1250	980	2.9	3.19
AGB-94	51	14	1600	1020	4.5	3.01
AGB-95	73	18	1550	1640	3.8	3.09
AGB-96	72	14	1700	1100	3.2	3.61
AGB-97	71	20	2100	1400	5.4	2.78
AGB-98	58	18	1800	1200	4.2	3.36
AGB-99	60	24	1800	1360	7.4	2.81
AGB-100	53	18	1800	1000	4.8	3.58
AGB-101	51	12	1600	1080	2.8	3.05
AGB-102	55	14	1425	920	3.7	3.53
AGB-103	48	12	1800	905	5.1	3.91
AGB-104	44	14	2000	750	4.5	3.90
AGB-105	40	10	1300	680	3.5	4.18
AGB-106	47	10	1300	720	2.2	3.89
AGB-107	49	12	1450	800	2.9	4.00
AGB-108	46	10	1450	650	3.4	3.92
AGB-109	67	16	1520	1040	2.0	3.49
AGB-110	62	20	1500	1440	2.1	3.46
AGB-111	80	14	1300	1480	1.1	2.83
AGB-112	63	13	1800	820	1.4	3.33
AGB-113	75	16	1350	1280	1.2	2.94
AGB-114	60	12	1100	790	1.2	3.09
AGB-115	54	14	1700	770	1.8	3.71
AGB-116	40	10	1650	770	2.0	4.46
AGB-117	58	14	1025	1100	1.4	3.70
AGB-118	48	20	3200	740	1.7	3.35
AGB-119	51	16	2700	720	2.0	3.78
AGB-120	54	14	2400	680	1.4	3.47
AGB-121	76	14	1325	1575	3.6	2.79
AGB-122	84	16	1625	920	3.4	2.82

SAMPLE	Cu (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	Mn (%)	Ash (%)
AGB-123	70	14	1600	1160	4.4	2.90
AGB-124	77	14	1800	740	4.3	2.77
AGB-125	72	14	1700	1200	4.2	3.02
AGB-126	62	12	1750	800	2.4	3.92
AGB-127	56	10	1500	920	2.3	3.78
AGB-128	68	12	1750	1020	4.1	4.10
AGB-129	64	12	1500	770	2.6	3.83
AGB-130	73	8	2400	720	2.8	3.60
AGB-131	66	11	2600	775	2.2	3.25
AGB-132	70	8	2100	740	2.0	3.38
AGB-133	60	8	2600	640	1.9	3.72
AGB-134	72	12	2500	920	1.7	3.70
AGB-135	67	12	2000	1300	2.0	2.68
AGB-136	49	8	2000	2000	1.0	3.93
AGB-137	61	10	1800	840	1.0	3.26
AGB-138	48	16	1950	2200	1.6	3.71
AGB-139	35	14	1450	550	1.7	4.50
AGB-140	57	16	1600	880	1.6	3.28
AGB-141	49	14	1400	880	1.2	3.61
AGB-142	60	13	1000	1280	1.9	3.41
AGB-143	68	16	850	1280	1.2	2.76
AGB-144	60	18	1000	1180	1.8	2.94
AGB-145	55	12	1250	830	1.9	3.49
AGB-146	59	17	1125	1180	1.4	3.13
AGB-147	46	14	1700	1050	2.1	3.38
AGB-148	66	12	1350	840	1.9	3.30
AGB-149	67	14	1900	920	1.1	2.91
AGB-150	56	12	1300	800	1.1	3.19
AGB-151	70	14	1150	960	1.2	2.88
AGB-152	65	8	1450	1160	1.4	3.25
AGB-153	47	12	925	710	1.2	3.58
AGB-154	40	14	1150	750	1.1	3.87
AGB-155	46	16	1400	840	1.1	3.17
AGB-156	45	14	1900	1280	1.2	3.25
AGB-157	54	12	2200	670	1.6	3.36
AGB-158	50	14	2200	1200	2.0	3.26
AGB-159	42	12	1700	740	1.8	3.73
AGB-160	50	12	1500	920	1.4	3.24
AGB-161	38	10	1600	770	1.8	3.63
AGB-162	52	12	925	920	0.9	3.09
AGB-163	58	16	1275	1410	1.0	3.23
AGB-164	46	10	700	930	0.9	3.44
AGB-165	38	14	775	780	0.7	3.73
AGB-166	38	10	1100	770	0.6	4.05
AGB-167	38	10	1150	1020	0.6	3.26
AGB-168	36	10	1350	880	0.9	3.97

SAMPLE	Cu (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	Mn (%)	Ash (%)
AGB-169	46	10	1100	5700	0.9	3.89
AGB-170	44	10	1600	1180	1.0	3.34
AGB-171	44	14	1800	980	1.0	3.60
AGB-172	52	12	2600	1040	0.8	3.00
AGB-173	54	10	2200	900	0.5	3.73
AGB-174	64	12	2400	1080	0.6	3.60
AGB-175	61	11	2750	1150	1.0	3.62
AGB-176	56	6	2100	1020	0.8	3.38
AGB-177	30	6	1500	525	1.2	4.15
AGB-178	36	12	1400	940	1.4	4.20
AGB-179	50	10	900	920	1.4	3.04
AGB-180	50	10	1600	1040	1.4	3.17
AGB-181	44	12	1300	1080	1.2	3.68
AGB-182	36	14	1700	740	2.1	3.50
AGB-183	44	10	1000	930	1.0	4.67
AGB-184	62	12	9000	1760	0.7	2.75
AGB-185	55	17	1100	1480	0.7	3.48
AGB-186	48	12	750	1360	0.6	3.32
AGB-187	48	12	950	980	0.9	2.78
AGB-188	42	12	1350	1360	0.8	3.37
AGB-189	38	8	800	1280	0.7	3.65
AGB-190	50	14	800	1100	0.7	3.05
AGB-191	52	12	625	2400	1.0	3.29
AGB-192	56	8	900	840	1.3	2.94
AGB-193	57	9	1000	1045	1.1	2.74
AGB-194	48	12	750	1150	1.7	3.31
AGB-195	54	6	900	860	1.0	2.71
AGB-196	46	8	750	780	1.1	3.25
AGB-197	60	12	1050	1040	0.9	3.65
AGB-198	48	14	800	840	1.5	3.70
AGB-200	52	12	1925	760	1.3	3.38
AGB-201	54	10	1950	1600	1.7	2.57
AGB-202	88	14	2000	1580	4.1	3.11
AGB-206	56	10	2050	850	3.1	4.99
AGB-210	44	10	2150	700	4.6	3.92
AGB-211	64	12	2800	880	6.2	3.70
AGB-222	79	20	1000	1840	0.9	2.61
AGB-223	48	10	1450	1040	1.6	4.01
AGB-227	60	10	1200	765	3.9	3.42
AGB-228	66	14	1400	1040	3.6	3.76
AGB-229	46	12	1650	700	4.4	3.65
AGB-230	44	16	1600	730	3.3	5.11
AGB-231	64	16	1700	790	5.6	3.12
AGB-232	58	10	1600	700	4.6	3.07
AGB-233	56	12	1950	720	5.5	3.20
AGB-234	78	8	1650	740	4.6	3.17

SAMPLE	Cu (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	Mn (%)	Ash (%)
AGB-235	50	8	1900	790	5.2	3.66
AGB-236	46	10	2025	685	7.3	3.21
AGB-237	58	14	1950	880	5.3	2.96
AGB-238	64	14	1800	880	5.3	3.36
AGB-239	52	2	2050	900	6.0	3.57
AGB-240	54	10	1800	1440	4.8	3.65
AGB-241	58	20	2050	700	6.0	3.32
AGB-242	62	8	1900	750	7.6	3.21
AGB-243	62	10	1950	650	7.0	3.32
AGB-244	62	12	1750	680	10.0	3.34
AGB-245	62	14	2100	780	7.4	3.10
AGB-246	65	10	2175	825	6.6	3.01
AGB-247	58	10	2650	700	3.8	3.52
AGB-248	56	10	2200	750	4.8	3.02
AGB-249	52	12	1800	685	4.0	3.25
AGB-250	38	10	1800	600	4.4	3.28
AGB-251	50	28	1800	1160	2.5	3.45
AGB-252	48	12	2700	690	7.7	3.95
AGB-253	50	10	1900	640	4.5	3.75
AGB-254	58	14	1850	870	5.1	3.24
AGB-255	52	10	1950	700	4.4	3.59
AGB-256	50	11	2850	710	5.2	3.04
AGB-257	48	18	2050	1120	4.8	3.09
AGB-258	54	14	2500	840	3.2	2.63
AGB 259	40	8	2900	650	5.0	3.88
AGB-260	52	12	2800	725	7.0	3.47
AGB-261	46	10	2600	690	4.0	3.71
AGB-262	58	14	2400	745	5.3	2.52
AGB-263	48	10	2100	700	4.2	3.06
AGB-266	48	14	1875	1090	7.7	3.39
AGB-267	54	12	2075	1140	7.4	2.87
AGB-268	44	14	2400	1160	8.8	2.65
AGB-269	68	15	2400	1150	7.7	2.18
AGB-270	48	14	2025	1120	5.6	2.70
AGB-271	62	18	180	1180	5.9	2.86
AGB-272	40	8	1900	880	7.3	3.51
AGB-273	38	12	1750	680	8.8	3.79
AGB-274	50	14	1925	765	7.3	3.32
AGB-275	40	14	1850	720	6.0	4.10
AGB-276	52	12	1600	680	5.1	3.27
AGB-277	42	14	2200	800	4.9	3.44
AGB-278	50	18	2100	850	6.8	3.17
AGB-279	46	12	1800	1280	3.3	3.59
AGB-280	48	20	2400	850	3.4	3.58
AGB-281	42	14	1900	640	3.6	3.57

SAMPLE	Cu (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	Mn (%)	Ash (%)
AGB-282	36	10	1550	525	3.4	4.44
AGB-283	44	12	1950	760	3.5	3.60
AGB-284	34	10	1950	450	5.4	4.19
AGB-285	44	13	1800	750	4.5	4.00
AGB-286	42	12	2050	600	3.7	4.74
AGB-288	42	14	2700	730	4.5	3.49
AGB-289	46	16	2500	750	3.8	4.45
AGB-290	42	12	2600	710	2.6	3.25
AGB-291	32	12	2700	550	3.6	5.29
AGB-292	40	8	2000	610	2.6	3.94
AGB-294	34	10	1950	640	2.9	4.48
AGB-295	54	16	3000	820	1.7	5.14
AGB-296	36	12	1575	655	4.7	4.12
AGB-297	32	10	1750	680	4.8	4.02
AGB-298	34	12	1950	720	3.2	4.23
AGB-299	52	12	1800	710	2.2	4.04
AGB-300	38	12	1500	620	5.4	3.74
AGB-301	34	10	1300	700	2.9	4.17
AGB-302	38	14	1650	740	7.0	3.70
AGB-303	36	10	1550	750	9.4	4.28
AGB-304	40	10	1800	920	8.6	3.21
AGB-305	50	12	1400	640	6.0	3.79
AGB-306	45	10	950	665	4.9	4.55
AGB-307	45	9	2000	630	6.2	4.07
AGB-308	56	11	2100	1100	6.0	3.24
AGB-309	45	7	1900	670	6.0	4.08
AGB-310	59	9	1850	770	6.3	3.23
AGB-311	42	8	2150	650	6.5	4.21
AGB-312	33	8	1350	475	3.0	3.63
AGB-313	53	12	2600	880	3.3	3.17
AGB-314	47	7	2000	710	4.4	3.62
AGB-315	55	10	1925	735	3.2	3.40
AGB-316	43	9	1950	615	4.8	3.75
AGB-317	36	8	2100	525	4.6	4.22
AGB-318	36	9	1750	575	3.8	3.99
AGB-319	39	12	1800	610	3.0	4.09
AGB-320	38	11	1800	650	3.5	4.15
AGB-321	38	10	1800	700	4.4	4.74
AGB-322	45	13	1700	700	5.6	3.68
AGB-323	41	13	1300	700	6.2	3.68
AGB-324	50	9	1700	750	6.4	3.43
AGB-325	47	13	1725	1300	5.5	3.46
AGB-326	43	12	1700	1100	6.5	3.38
AGB-327	38	9	2000	600	3.8	4.08
AGB-328	48	9	1375	600	2.9	3.16
AGB-329	43	8	1700	625	8.4	3.56
AGB-330	44	13	1900	675	6.0	3.77

SAMPLE	Cu (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	Mn (%)	Ash (%)
AGB-331	42	10	1800	630	5.4	4.46
AGB-332	38	7	1700	550	4.4	4.56
AGB-333	44	8	1500	800	6.0	4.21
AGB-334	48	10	1800	1040	7.0	3.34
AGB-335	55	10	1800	1020	8.2	3.49
AGB-336	59	13	1875	1050	9.3	3.07
AGB-337	50	14	1900	920	10.0	2.84
AGB-338	67	12	1900	820	6.0	2.93
AGB-339	42	9	1950	525	5.0	5.41
AGB-340	39	9	1900	550	8.8	4.04
AGB-341	50	9	2900	675	4.6	3.98
AGB-342	60	12	1800	650	5.1	4.80
AGB-343	51	7	2150	675	4.9	4.00
AGB-344	41	9	1675	2300	5.2	4.91
AGB-345	42	9	2100	700	4.9	4.38
AGB-346	44	8	1700	920	5.3	3.17
AGB-347	53	11	1425	1040	5.6	2.84
AGB-348	55	11	1800	960	6.4	3.47
AGB-349	44	7	1650	780	5.6	3.21
AGB-350	52	14	1800	1100	4.8	3.67

Agassiz Biogeochemistry
Black Spruce (*Picea marisna*) Needles Cu, Pb, Zn, Fe (ppm) Mn, Ash (%) (AAS)
Duplicate Reproducibility

SAMPLE	Cu (ppm)		Pb (ppm)		Zn (ppm)		Mn (%)		Fe (ppm)		Ash (%)	
	1	2	1	2	1	2	1	2	1	2	1	2
AGB-31	44	56	13	14	2000	2200	2.6	2.8	960	860	3.50	3.07
AGB-35	58	51	14	14	2100	2100	3.5	3.5	840	740	3.79	3.91
AGB-46	44	48	14	16	1800	1800	2.6	2.7	690	710	3.69	3.67
AGB-73	54	54	14	18	1825	1750	4.7	4.6	900	1080	3.21	3.21
AGB-83	42	43	12	12	1600	1750	2.0	2.5	730	720	3.80	3.85
AGB-90	50	42	14	11	1650	1400	6.4	5.8	720	600	4.28	3.80
AGB-103	52	44	12	12	1800	1800	5.3	4.9	1040	770	3.92	3.90
AGB-112	59	67	13	14	1800	1800	1.4	1.4	820	820	3.32	3.33
AGB-121	78	73	10	18	1350	1300	4.0	3.2	1520	1630	2.81	2.76
AGB-131	66	65	10	12	2500	2700	2.0	2.3	800	750	3.21	3.29
AGB-146	55	63	18	16	1300	950	1.6	1.2	1120	1240	3.50	2.76
AGB-153	46	48	12	12	950	900	1.3	1.2	700	720	3.58	3.58
AGB-163	62	54	16	16	1200	1350	1.0	1.0	1340	1480	3.16	3.29
AGB-175	64	58	10	12	2700	2800	1.1	1.0	1100	1200	3.40	3.84
AGB-185	62	48	16	18	1100	1100	0.7	0.8	1600	1360	3.60	3.35
AGB-193	54	68	8	10	1000	1000	1.1	1.2	1040	1050	2.82	2.66
AGB-236	50	42	12	8	2000	2050	7.0	7.6	700	670	3.09	3.33
AGB-246	66	64	10	10	2150	2200	6.2	7.0	980	670	3.11	2.91
AGB-256	46	54	12	10	2900	2800	5.2	5.3	680	740	3.05	3.04
AGB-266	46	50	12	16	2000	1750	7.8	7.5	1120	1060	3.32	3.46
AGB-274	48	52	18	10	1950	1900	7.2	7.4	740	790	3.34	3.29
AGB-285	46	42	12	14	1800	1800	4.3	4.7	740	760	4.03	3.96
AGB-296	36	36	10	14	1500	1650	4.3	5.1	650	660	4.04	4.15
AGB-306	42	47	8	11	950	950	5.0	4.8	635	700	4.69	4.41
AGB-315	56	54	12	8	1950	1900	3.3	3.0	780	690	3.39	3.41
AGB-325	47	46	12	13	1700	1750	5.3	5.7	1400	1200	3.55	3.36
AGB-336	60	58	12	13	1850	1900	9.0	9.6	1060	1040	3.20	2.93
AGB-347	53	52	11	10	1500	1350	5.8	5.3	1120	960	2.74	2.93

Agassiz Biogeochemistry - Raw Data
Black Spruce (Picea mariana) Twigs As (ppm), Au (ppb)
by INAA (Dry Sample)
nd - not detected, below the limits of detection for this analytical method

SAMPLE	As (ppm)	Au (ppb)	SAMPLE	As (ppm)	Au (ppb)
AGB-31	0.47	1.1	AGB-83	0.26	0.6
AGB-33	0.36	1.4	AGB-84	0.40	1.5
AGB-34	0.33	0.6	AGB-85	0.25	2.2
AGB-35	0.28	1.0	AGB-86	0.33	1.4
AGB-36	0.29	0.6	AGB-87	0.23	1.1
AGB-38	0.31	1.0	AGB-88	0.17	1.0
AGB-39	0.24	0.5	AGB-89	0.23	0.8
AGB-40	0.21	0.6	AGB-90	0.24	0.9
AGB-41	0.26	1.1	AGB-91	0.19	0.8
AGB-43	0.24	0.6	AGB-92	0.17	0.5
AGB-44	0.20	0.3	AGB-93	0.22	0.9
AGB-45	4.40	1.2	AGB-94	0.23	1.1
AGB-46	0.30	0.6	AGB-95	0.19	0.6
AGB-47	0.26	0.7	AGB-96	0.16	0.5
AGB-48	0.24	1.2	AGB-97	0.23	1.2
AGB-49	0.28	0.5	AGB-98	0.26	0.9
AGB-50	0.22	0.9	AGB-99	0.24	1.4
AGB-51	0.19	0.6	AGB-100	0.31	1.0
AGB-52	0.24	1.0	AGB-101	0.31	0.6
AGB-53	0.28	0.7	AGB-102	0.23	0.8
AGB-54	0.27	1.2	AGB-103	0.23	0.9
AGB-55	0.19	0.7	AGB-104	0.34	1.0
AGB-56	0.26	0.8	AGB-105	0.26	0.8
AGB-57	0.21	0.7	AGB-106	0.32	0.5
AGB-58	0.22	1.1	AGB-107	0.26	0.8
AGB-59	0.23	0.8	AGB-108	0.30	0.7
AGB-60	0.25	1.0	AGB-109	0.22	0.5
AGB-61	0.20	0.5	AGB-110	0.24	0.3
AGB-62	0.29	0.4	AGB-111	0.24	0.5
AGB-63	0.23	0.2	AGB-112	0.30	0.7
AGB-64	0.36	0.9	AGB-113	0.22	0.4
AGB-65	0.34	0.7	AGB-114	0.21	0.4
AGB-66	0.29	0.6	AGB-115	0.19	0.9
AGB-67	0.34	0.4	AGB-116	0.14	0.2
AGB-68	0.18	0.2	AGB-117	0.13	0.3
AGB-69	0.18	0.5	AGB-118	0.23	1.2
AGB-70	0.22	0.9	AGB-119	0.24	1.6
AGB-71	0.23	0.9	AGB-120	0.20	0.3
AGB-72	0.32	1.5	AGB-121	0.15	0.5
AGB-73	0.28	0.8	AGB-122	0.20	0.9
AGB-74	0.16	0.4	AGB-123	0.15	0.3
AGB-75	0.20	0.4	AGB-124	0.19	0.6
AGB-76	0.17	0.2	AGB-125	0.27	0.5
AGB-77	0.22	1.2	AGB-126	0.24	0.4
AGB-78	0.29	0.5	AGB-127	0.24	0.5
AGB-79	0.33	1.0	AGB-128	0.24	0.4
AGB-80	0.36	1.6			
AGB-81	0.41	0.7			
AGB-82	0.24	0.3			

SAMPLE	As (ppm)	Au (ppb)	SAMPLE	As (ppm)	Au (ppb)
AGB-129	0.18	0.6	AGB-176	0.17	0.5
AGB-130	0.20	0.2	AGB-177	0.15	0.5
AGB-131	0.20	0.8	AGB-178	0.29	0.5
AGB-132	0.27	0.3	AGB-179	0.14	0.4
AGB-133	0.19	0.3	AGB-180	0.29	1.3
AGB-134	0.12	0.3	AGB-181	0.25	0.7
AGB-135	0.25	1.4	AGB-182	0.32	0.6
AGB-136	0.19	0.9	AGB-183	0.23	0.5
AGB-137	0.20	0.7	AGB-184	0.19	0.7
AGB-138	0.24	1.0	AGB-185	0.21	0.6
AGB-139	0.20	0.4	AGB-186	0.21	0.7
AGB-140	0.23	1.0	AGB-187	0.14	0.4
AGB-141	0.24	1.2	AGB-188	0.22	0.5
AGB-142	0.25	0.5	AGB-189	0.21	0.5
AGB-143	0.25	0.8	AGB-190	0.24	0.7
AGB-144	0.26	1.6	AGB-191	0.22	0.4
AGB-145	0.19	1.5	AGB-192	0.16	0.3
AGB-146	0.30	1.3	AGB-193	0.15	0.6
AGB-147	0.27	0.8	AGB-194	0.20	0.7
AGB-148	0.16	0.7	AGB-195	0.13	0.5
AGB-149	0.29	1.1	AGB-196	0.16	0.5
AGB-150	0.31	0.6	AGB-197	0.22	0.4
AGB-151	0.26	1.0	AGB-198	0.24	0.6
AGB-152	0.35	0.9	AGB-200	0.30	1.1
AGB-153	0.32	2.2	AGB-201	0.23	0.5
AGB-154	0.36	2.5	AGB-202	0.32	0.7
AGB-155	0.33	1.6	AGB-203	0.35	0.5
AGB-156	0.28	0.9	AGB-204	0.23	0.4
AGB-157	0.23	0.3	AGB-205	0.26	0.6
AGB-158	0.24	1.0	AGB-206	0.33	0.5
AGB-159	0.28	0.6	AGB-207	0.22	0.5
AGB-160	0.23	0.7	AGB-208	0.23	0.5
AGB-161	0.31	0.6	AGB-209	0.20	0.7
AGB-162	0.23	1.1	AGB-210	0.25	0.5
AGB-163	0.42	1.2	AGB-211	0.28	0.6
AGB-164	0.27	1.0	AGB-212	0.08	0.2
AGB-165	0.29	1.0	AGB-213	0.17	0.3
AGB-166	0.31	0.8	AGB-214	0.13	0.3
AGB-167	0.33	0.8	AGB-215	0.13	0.1
AGB-168	0.51	1.2	AGB-216	0.17	0.3
AGB-169	0.36	0.5	AGB-217	0.11	0.4
AGB-170	0.50	1.0	AGB-218	0.15	0.2
AGB-171	0.37	0.7	AGB-219	0.12	0.4
AGB-172	0.35	0.8	AGB-220	0.15	0.4
AGB-173	0.20	0.4	AGB-221	0.19	0.3
AGB-174	0.18	0.9	AGB-222	0.14	0.6
AGB-175	0.30	0.8	AGB-223	0.19	0.4

SAMPLE	As (ppm)	Au (ppb)	SAMPLE	As (ppm)	Au (ppb)
AGB-224	0.19	0.4	AGB-273	0.21	0.2
AGB-225	0.21	0.4	AGB-274	0.22	0.5
AGB-226	0.21	0.4	AGB-275	0.20	0.5
AGB-227	0.26	2.1	AGB-276	0.19	0.2
AGB-228	0.21	0.5	AGB-277	0.22	0.3
AGB-229	0.20	0.6	AGB-278	0.28	0.4
AGB-230	0.24	0.7	AGB-279	0.25	0.3
AGB-231	0.19	0.6	AGB-280	0.15	0.7
AGB-232	0.19	0.5	AGB-281	0.14	0.4
AGB-233	0.22	0.5	AGB-282	0.17	0.9
AGB-234	0.23	0.6	AGB-283	0.14	0.6
AGB-235	0.25	0.5	AGB-284	0.13	3.8
AGB-236	0.41	0.4	AGB-285	0.20	0.4
AGB-237	0.28	0.5	AGB-286	0.11	0.6
AGB-238	0.37	0.5	AGB-288	0.13	0.8
AGB-239	0.44	1.4	AGB-289	0.11	0.5
AGB-240	0.34	0.5	AGB-290	0.17	0.8
AGB-241	0.24	0.3	AGB-291	0.18	0.9
AGB-242	0.27	0.1	AGB-292	0.12	0.6
AGB-243	0.24	0.4	AGB-294	0.16	0.9
AGB-244	0.21	0.3	AGB-295	0.17	0.4
AGB-245	0.21	0.3	AGB-296	0.13	0.5
AGB-246	0.22	0.4	AGB-297	0.23	0.6
AGB-247	0.26	2.8	AGB-298	0.16	0.6
AGB-248	0.29	1.0	AGB-299	0.23	1.4
AGB-249	0.31	0.4	AGB-300	0.21	0.7
AGB-250	0.23	0.3	AGB-301	0.20	1.0
AGB-251	0.24	0.4	AGB-302	0.22	0.5
AGB-252	0.33	0.4	AGB-303	0.20	1.0
AGB-253	0.32	0.7	AGB-304	0.22	0.4
AGB-254	0.26	0.4	AGB-305	0.20	1.0
AGB-255	0.22	0.3	AGB-306	0.21	0.4
AGB-256	0.24	0.3	AGB-307	0.24	0.4
AGB-257	0.26	0.4	AGB-308	0.23	0.3
AGB-258	0.20	0.9	AGB-309	8.7	2.8
AGB-259	0.27	0.5	AGB-310	1.5	1.0
AGB-260	0.22	0.4	AGB-311	0.55	0.6
AGB-261	0.19	0.3	AGB-312	0.43	0.4
AGB-262	0.21	0.4	AGB-313	0.36	0.6
AGB-263	0.19	0.3	AGB-314	0.30	0.4
AGB-266	0.23	0.5	AGB-315	0.21	0.4
AGB-267	0.24	0.7	AGB-316	0.22	0.2
AGB-268	0.23	0.3	AGB-317	0.28	0.5
AGB-269	0.28	0.5	AGB-318	0.24	0.2
AGB-270	0.30	0.3	AGB-319	0.19	0.2
AGB-271	0.22	nd	AGB-320	0.15	0.2
AGB-272	0.26	0.4	AGB-321	0.38	0.3

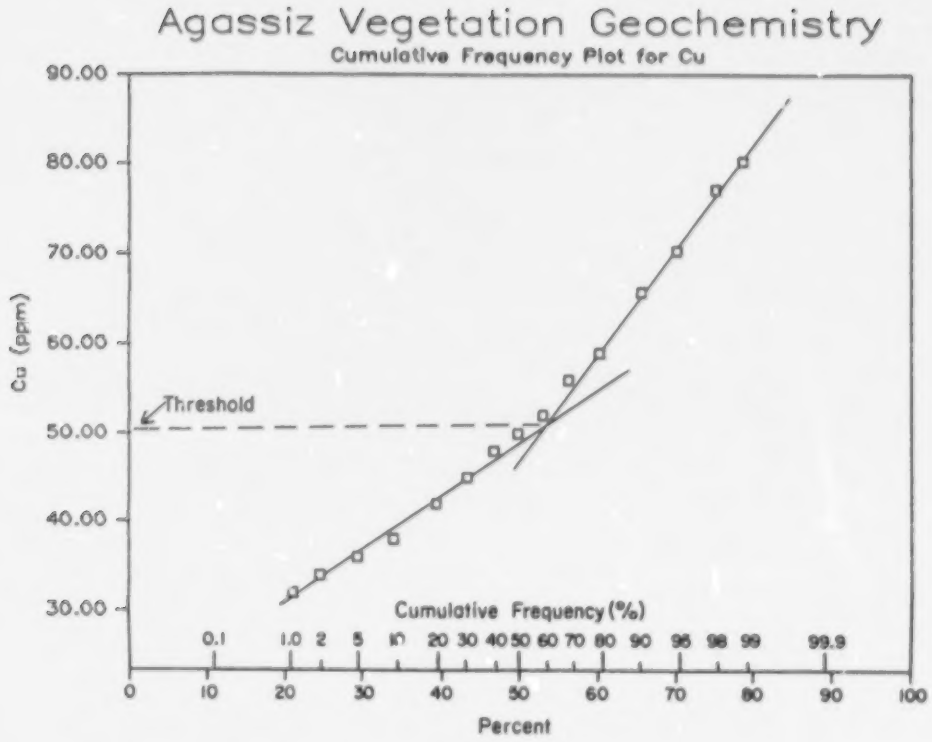
SAMPLE	As (ppm)	Au (ppb)
AGB-322	0.17	0.3
AGB-323	0.18	0.3
AGB-324	0.25	0.3
AGB-325	0.24	0.3
AGB-326	0.21	0.3
AGB-327	0.23	nd
AGB-328	0.19	0.1
AGB-329	0.15	0.2
AGB-330	0.15	0.6
AGB-331	0.25	0.3
AGB-332	0.25	0.1
AGB-333	0.20	0.2
AGB-334	0.20	nd
AGB-335	0.20	0.3
AGB-336	0.25	0.4
AGB-337	0.22	0.3
AGB-338	0.19	0.9
AGB-339	0.22	0.4
AGB-340	0.19	0.4
AGB-341	0.18	0.5
AGB-342	0.20	0.2
AGB-343	0.19	0.4
AGB-344	0.21	0.4
AGB-345	0.25	0.4
AGB-346	0.19	0.2
AGB-347	0.23	0.4
AGB-348	0.21	0.4
AGB-349	0.23	0.6
AGB-350	0.24	0.2

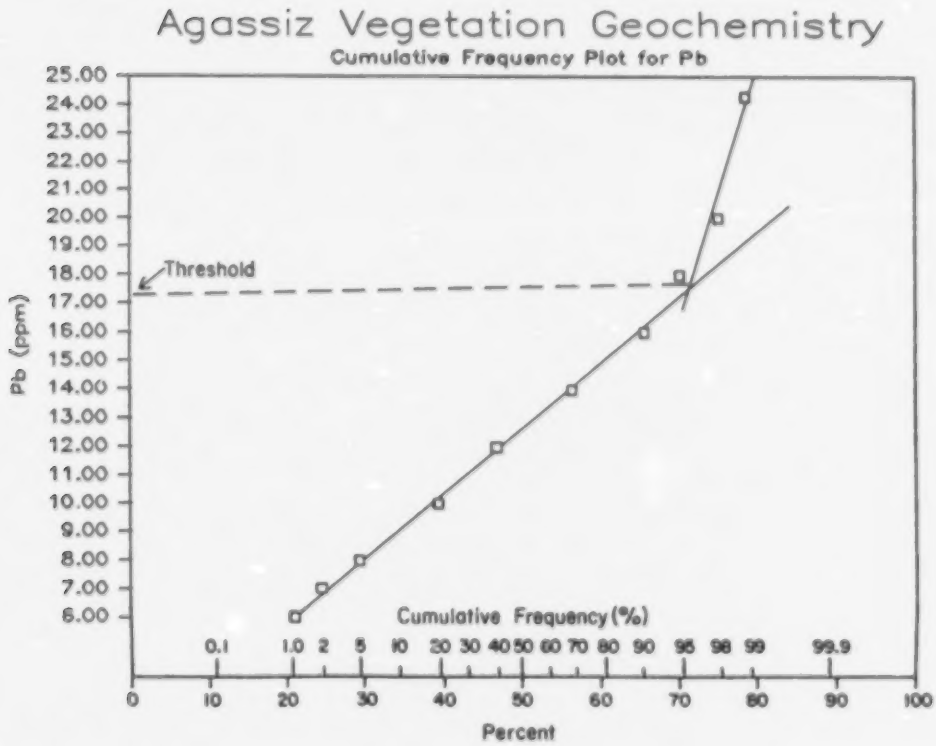
Agassiz Biogeochemistry
Black Spruce (Picea mariana) Twigs
Au (ppb), As (ppm) (INAA) (Dry Sample)
Duplicate Reproducibility

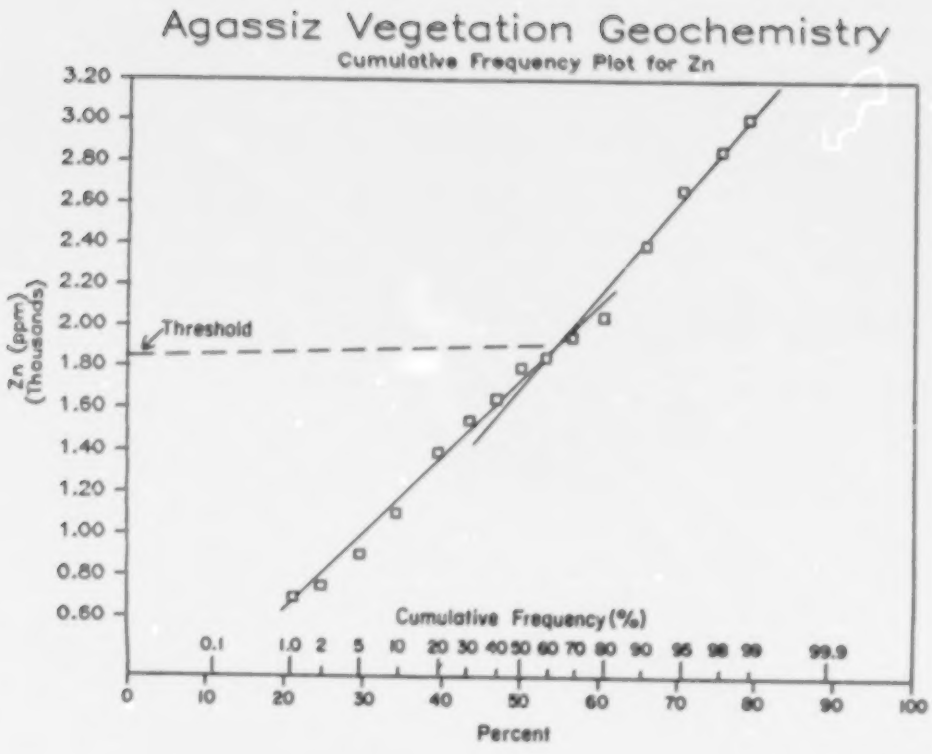
SAMPLE	As (ppm)		Au (ppb)	
	1	2	1	2
AGB-35	0.29	0.27	0.9	1.0
AGB-46	0.32	0.28	0.5	0.4
AGB-73	0.27	0.29	0.6	0.9
AGB-83	0.24	0.27	0.6	0.6
AGB-103	0.22	0.24	1.0	0.7
AGB-112	0.30	0.29	0.8	0.5
AGB-121	0.15	0.15	0.5	0.4
AGB-131	0.19	0.20	0.5	1.0
AGB-146	0.26	0.33	1.2	1.3
AGB-153	0.31	0.32	1.5	2.9
AGB-163	0.52	0.31	1.8	0.5
AGB-175	0.33	0.26	0.5	1.1
AGB-185	0.19	0.22	0.3	0.8
AGB-193	0.13	0.16	0.8	0.4
AGB-236	0.43	0.38	0.5	0.3
AGB-246	0.23	0.20	0.3	0.4
AGB-256	0.27	0.20	0.2	0.3
AGB-266	0.20	0.26	0.4	0.5
AGB-274	0.20	0.24	0.3	0.6
AGB-306	0.18	0.23	0.3	0.5
AGB-315	0.24	0.18	0.4	0.4
AGB-325	0.25	0.23	0.3	0.2
AGB-336	0.19	0.31	0.3	0.4
AGB-347	0.23	0.23	0.4	0.4

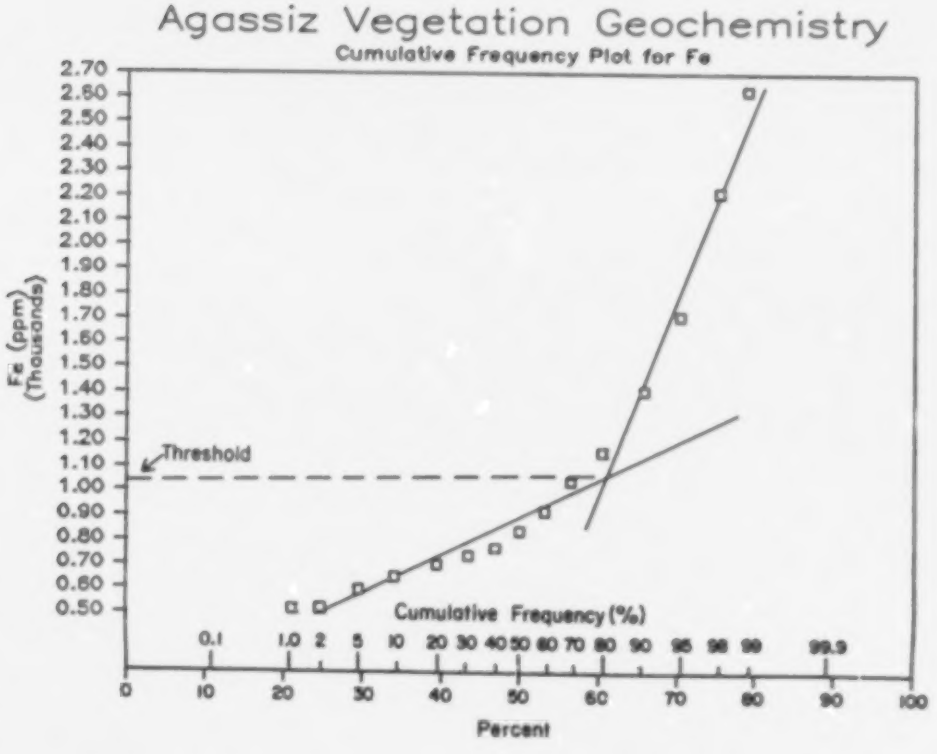
APPENDIX 2

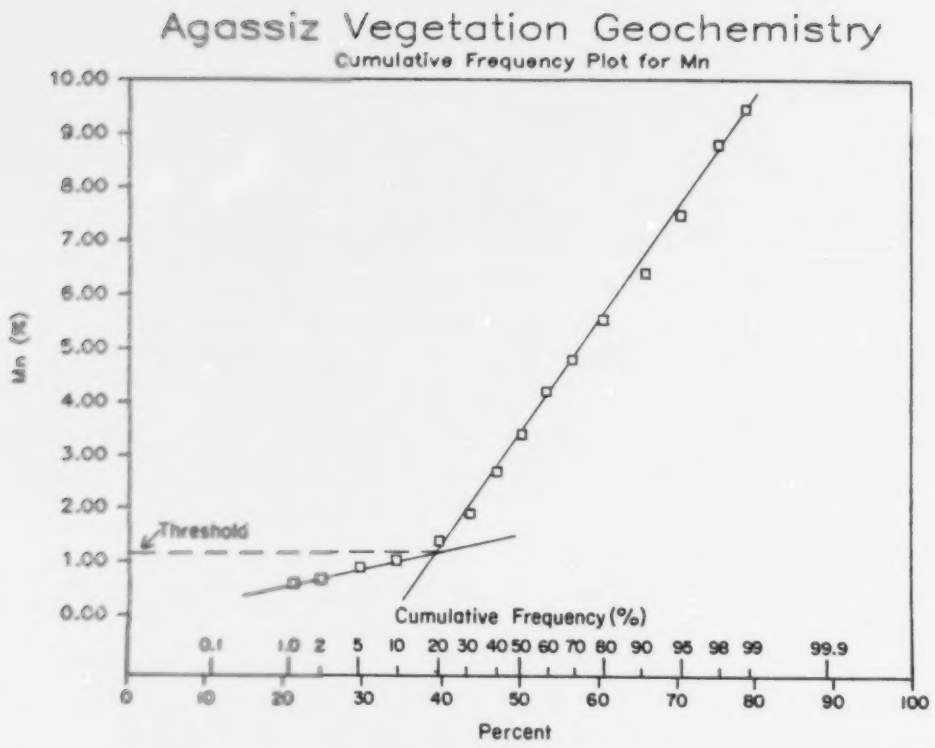
Cumulative Frequency Plots

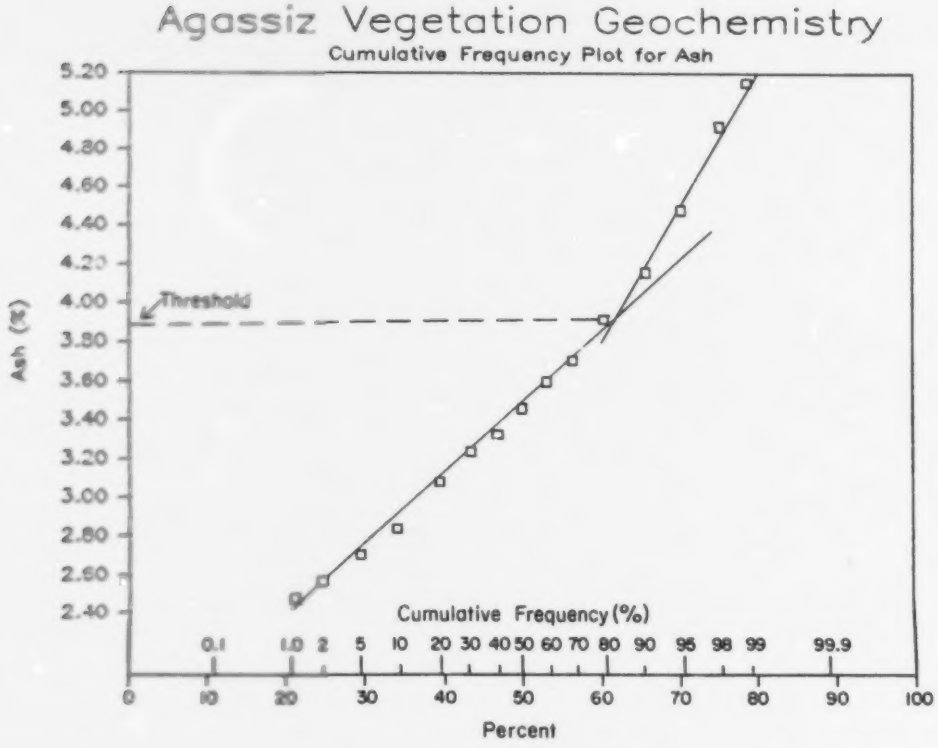

Agassiz Vegetation Geochemistry
Cumulative Frequency Plot for Cu
Cu (ppm)
90.00
80.00
70.00
60.00
50.00
40.00
30.00
Threshold
Cumulative Frequency (%)
0.1 1.0 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.9
0 10 20 30 40 50 60 70 80 90 100
Percent

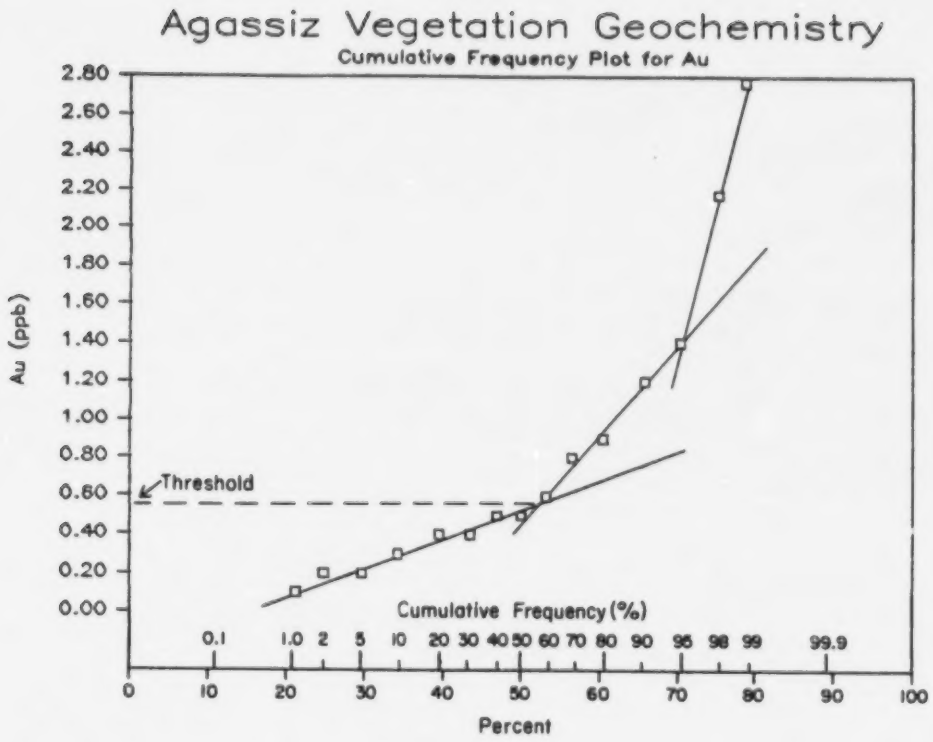

Agassiz Vegetation Geochemistry
Cumulative Frequency Plot for Pb
Pb (ppm)
25.00
24.00
23.00
22.00
21.00
20.00
19.00
18.00
17.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
Threshold
Cumulative Frequency (%)
0.1 1.0 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.9
0 10 20 30 40 50 60 70 80 90 100
Percent

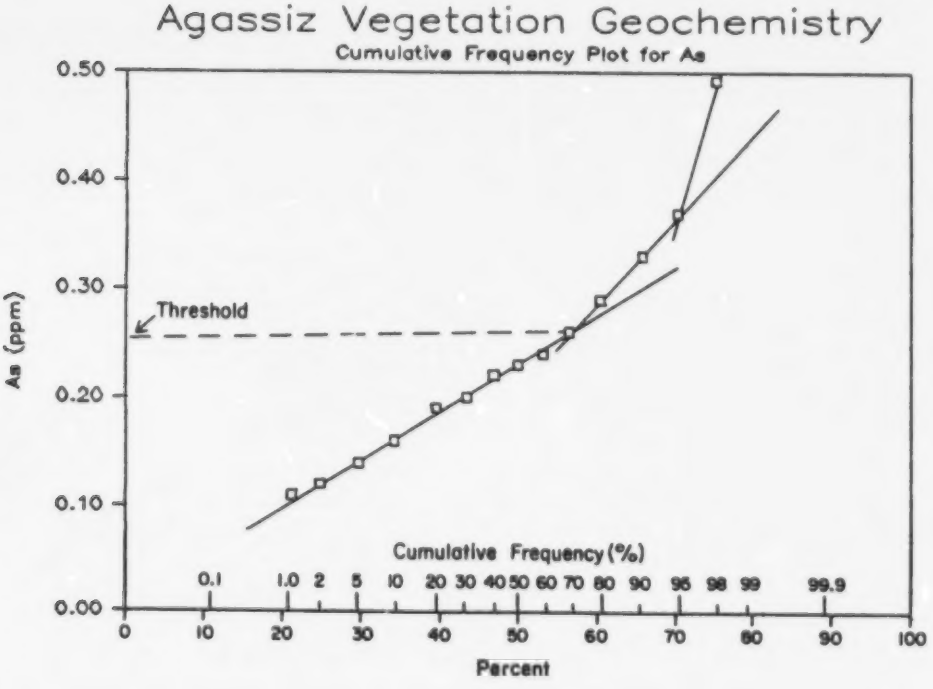

Agassiz Vegetation Geochemistry
Cumulative Frequency Plot for Zn
Zn (ppm) (Thousands)
3.20
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
Threshold
Cumulative Frequency (%)
0.1 1.0 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.9
0 10 20 30 40 50 60 70 80 90 100
Percent


Agassiz Vegetation Geochemistry
Cumulative Frequency Plot for Fe
Fe (ppm) (Thousands)
2.70
2.60
2.50
2.40
2.30
2.20
2.10
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
Threshold
Cumulative Frequency (%)
0.1 1.0 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.9
0 10 20 30 40 50 60 70 80 90 100
Percent


Agassiz Vegetation Geochemistry
Cumulative Frequency Plot for Mn
Mn (%)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Threshold
Cumulative Frequency (%)
0.1 1.0 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.9
0 10 20 30 40 50 60 70 80 90 100
Percent


Agassiz Vegetation Geochemistry
Cumulative Frequency Plot for Ash
Ash (%)
5.20
5.00
4.80
4.60
4.40
4.20
4.00
3.80
3.60
3.40
3.20
3.00
2.80
2.60
2.40
Threshold
Cumulative Frequency (%)
0.1 1.0 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.9
0 10 20 30 40 50 60 70 80 90 100
Percent

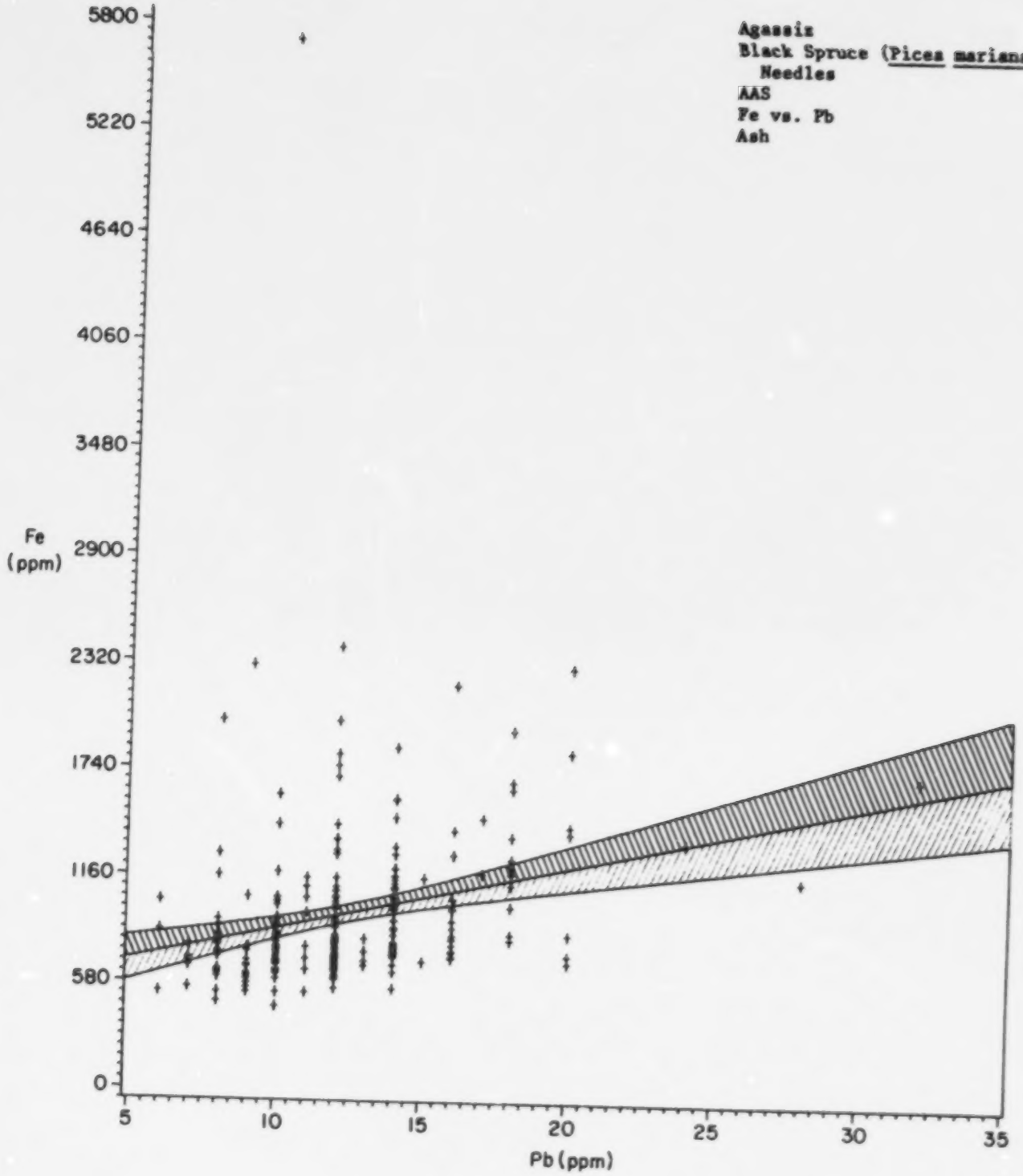

Agassiz Vegetation Geochemistry
Cumulative Frequency Plot for Au
Au (ppb)
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Threshold
Cumulative Frequency (%)
0.1 1.0 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.9
0 10 20 30 40 50 60 70 80 90 100
Percent

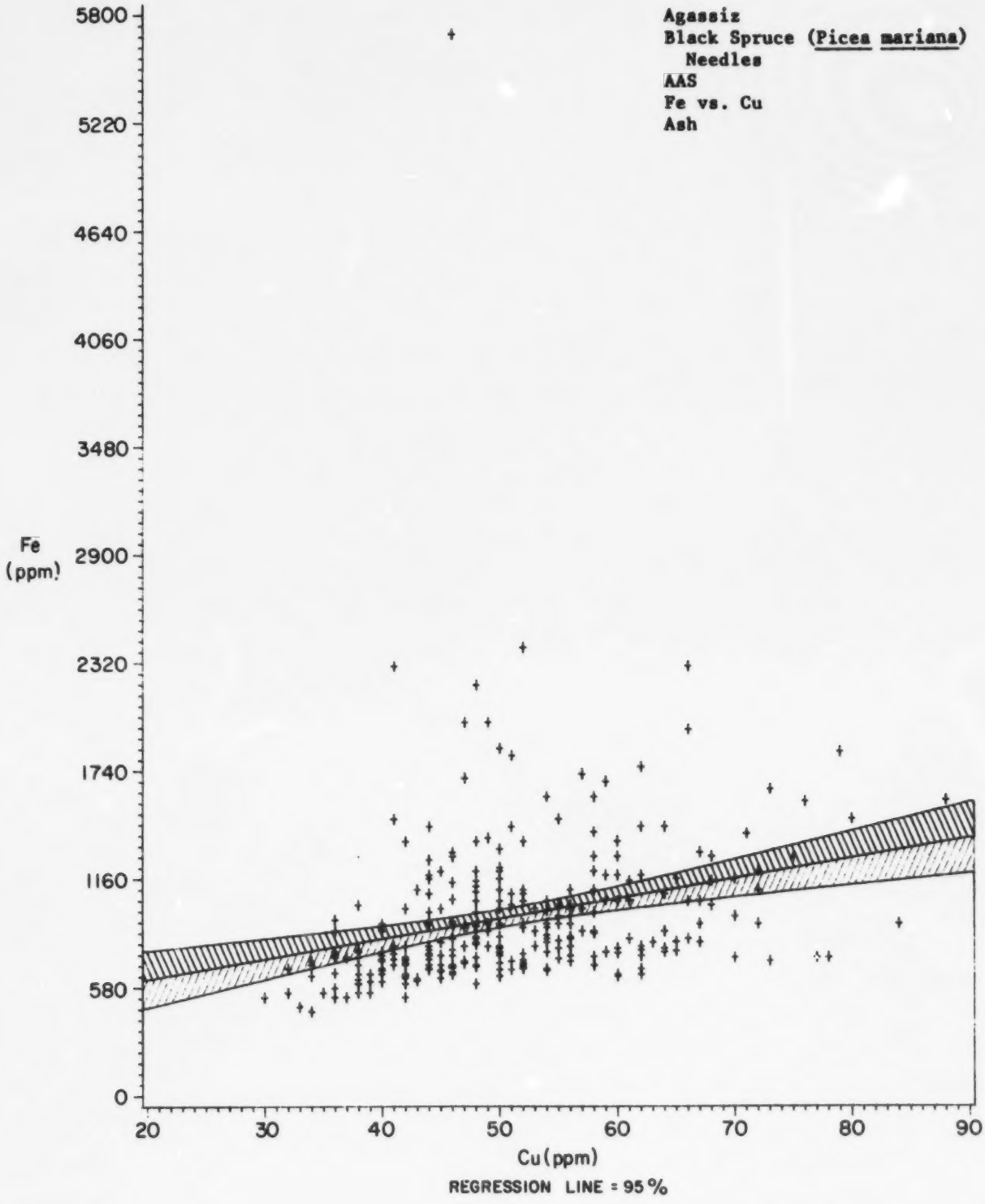

Agassiz Vegetation Geochemistry
Cumulative Frequency Plot for As
As (ppm)
0.50
0.40
0.30
0.20
0.10
0.00
Threshold
Cumulative Frequency (%)
0.1 1.0 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.9
0 10 20 30 40 50 60 70 80 90 100
Percent

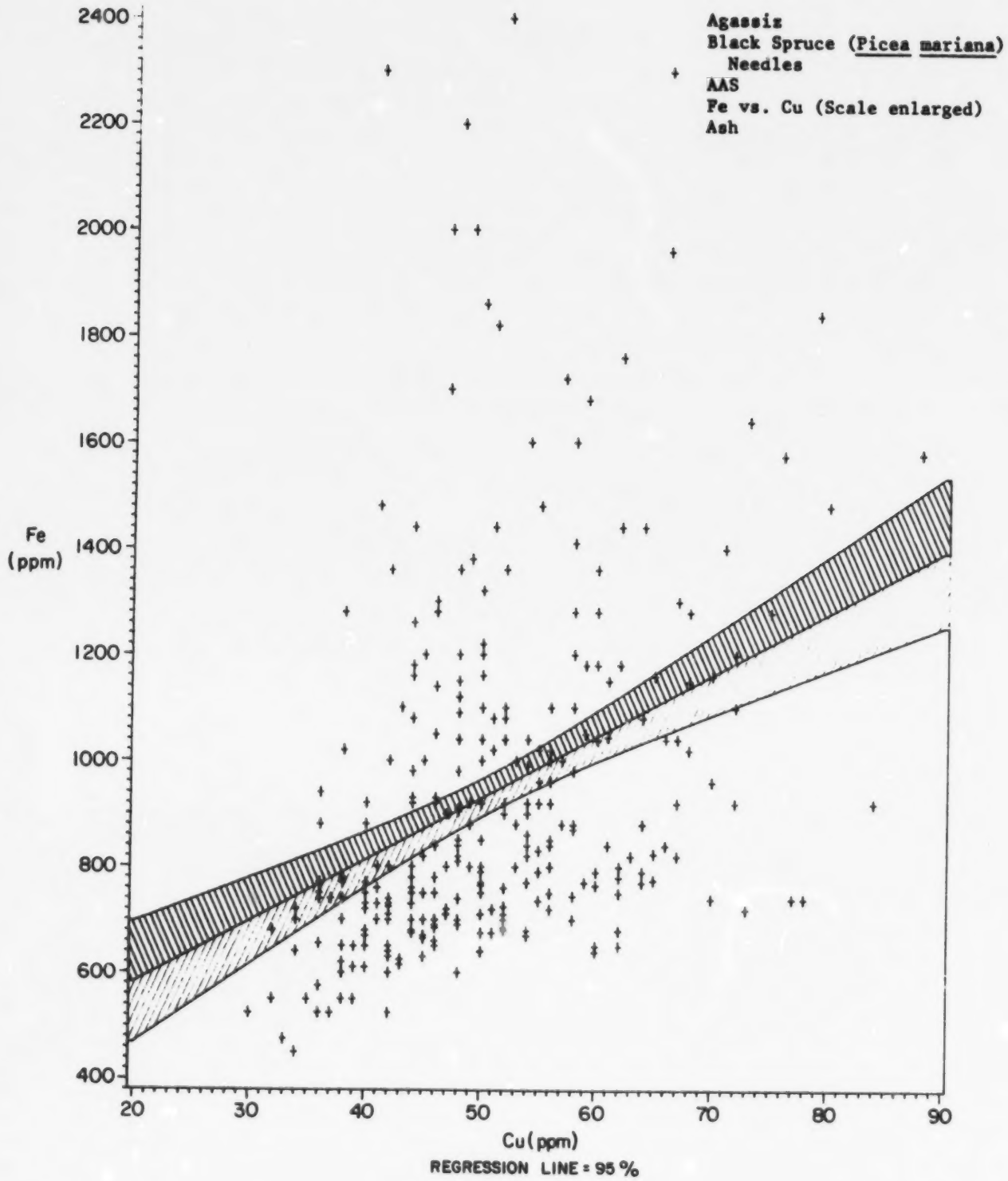
APPENDIX 3 - Part 1

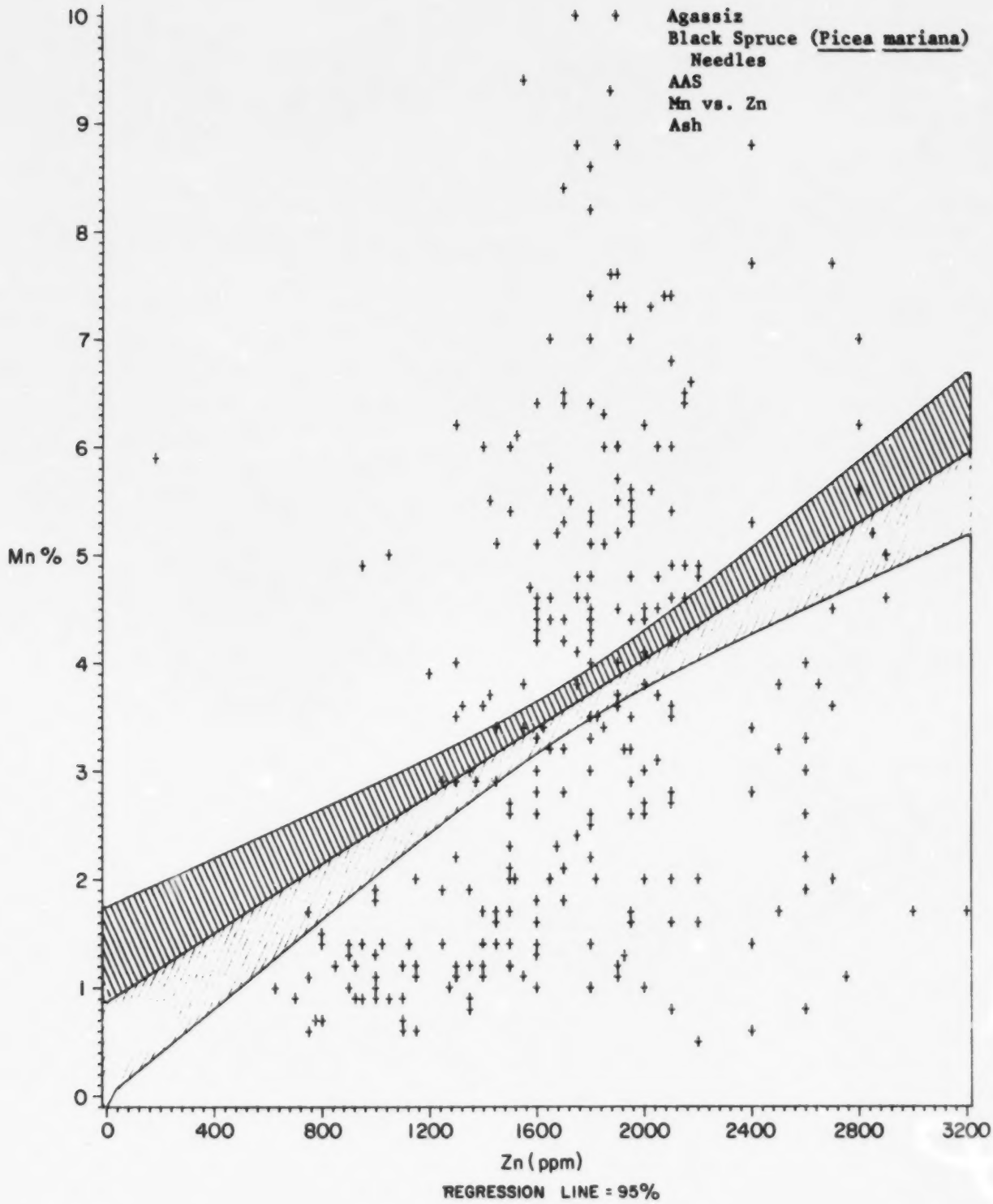
X-Y Element Plots

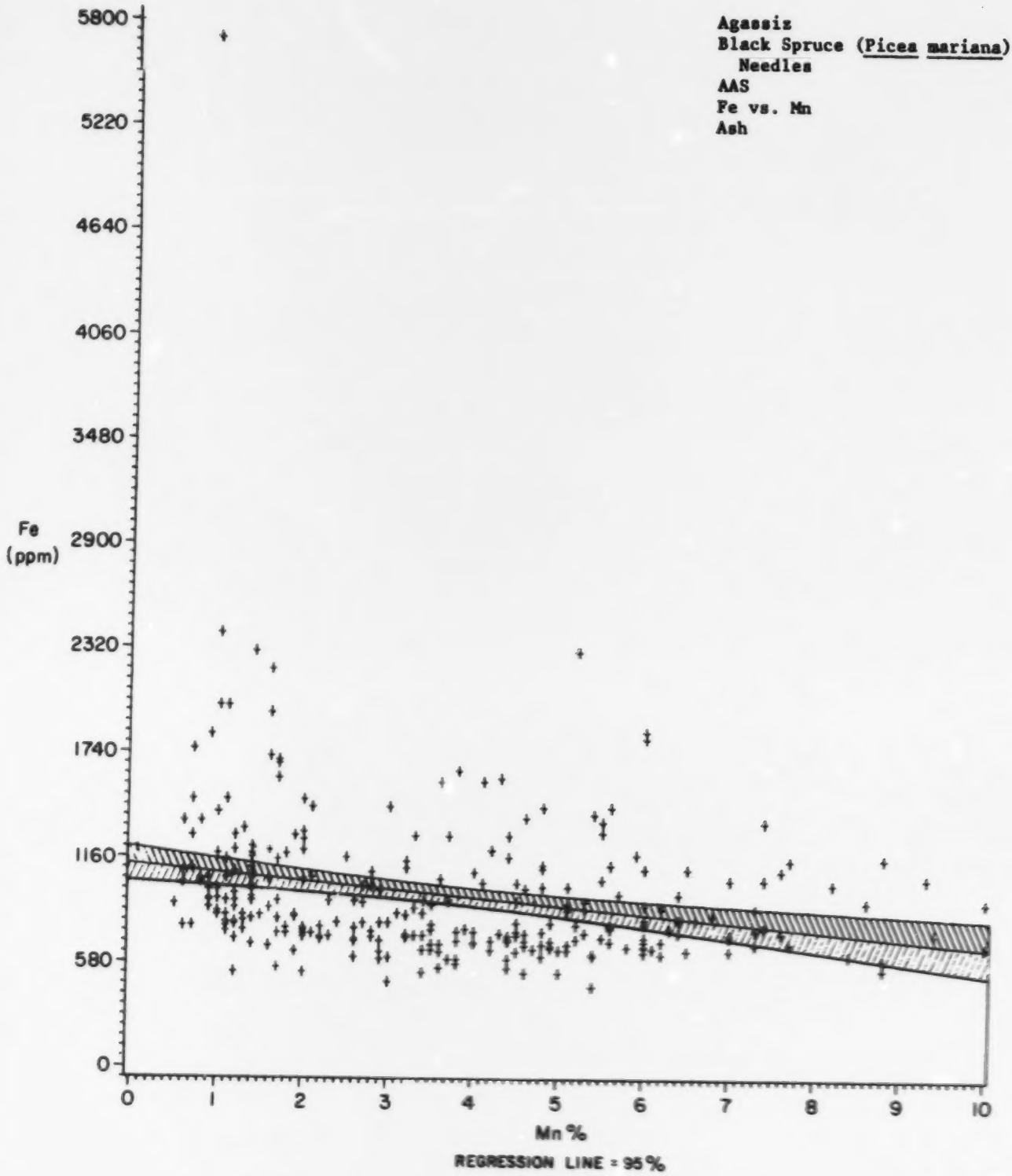
Agassiz Black Spruce Needles

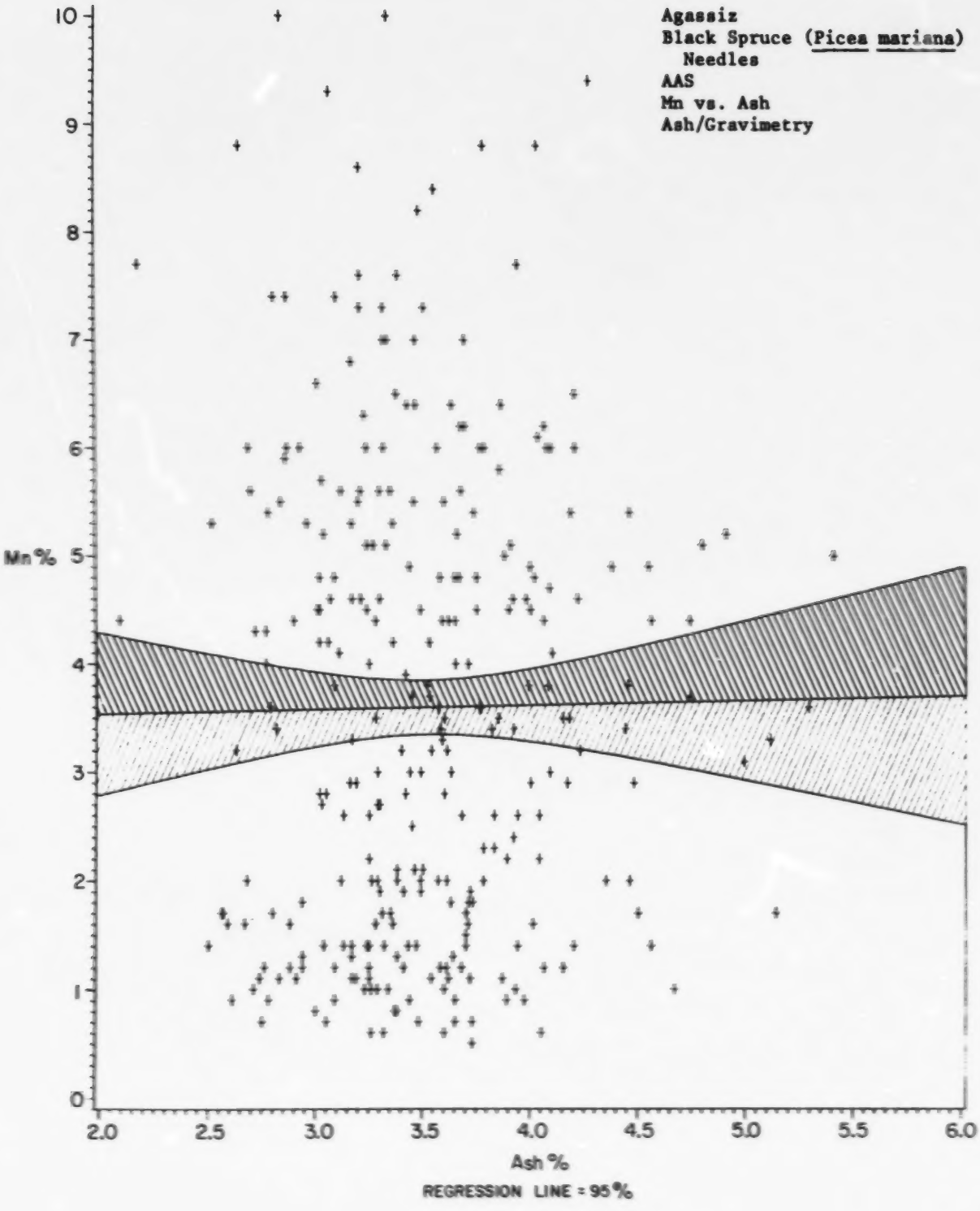

Agassiz
Black Spruce (Picea mariana)
Needles
AAS
Fe vs. Pb
Ash
5800
5220
4640
4060
3480
2900
2320
1740
1160
580
0
Fe (ppm)
5
10
15
20
25
30
35
Pb (ppm)

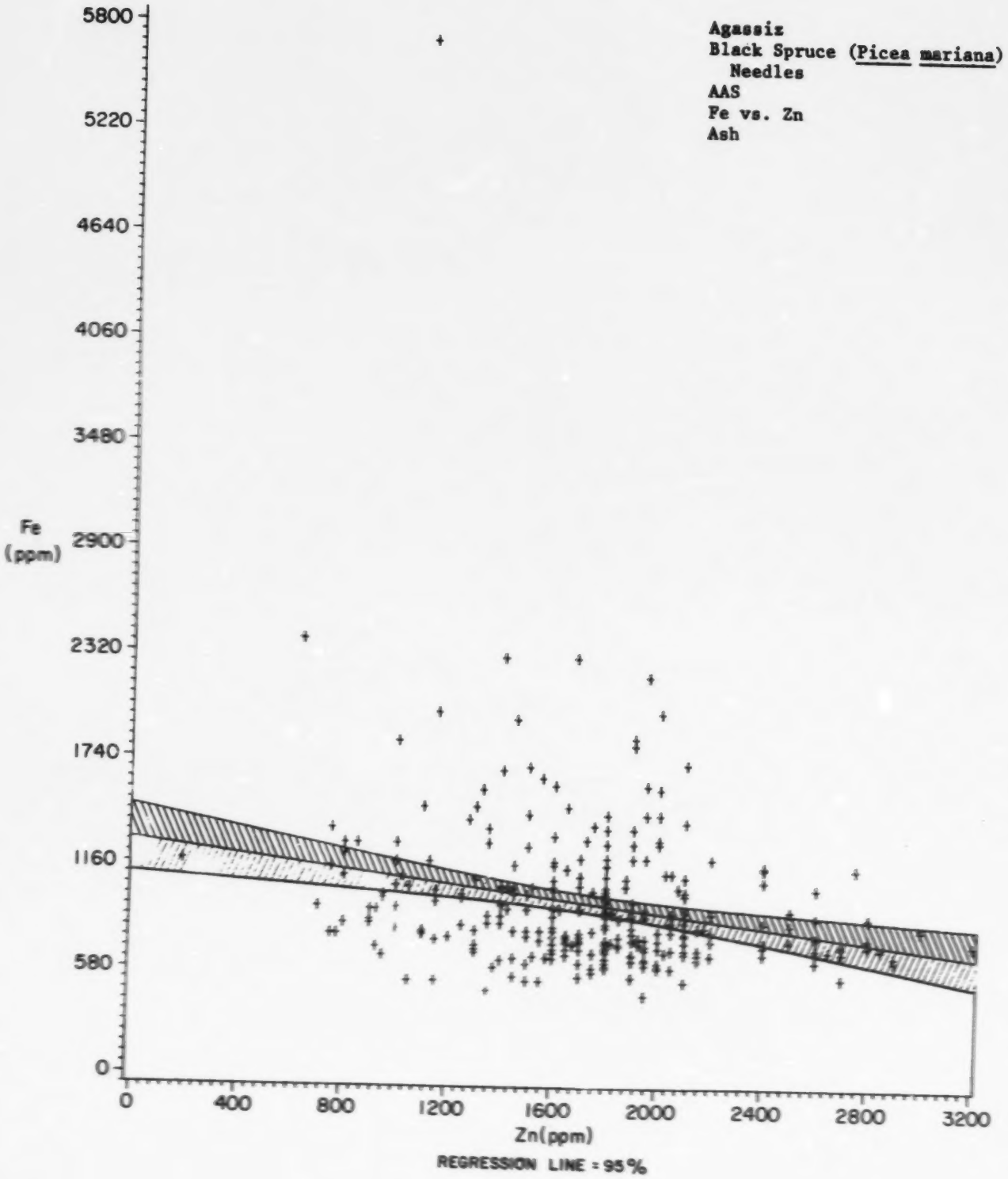

Agassiz
Black Spruce (Picea mariana)
Needles
AAS
Fe vs. Cu
Ash
5800
5220
4640
4060
3480
2900
2320
1740
1160
580
0
Fe
(ppm)
20
30
40
50
60
70
80
90
Cu(ppm)
REGRESSION LINE = 95%

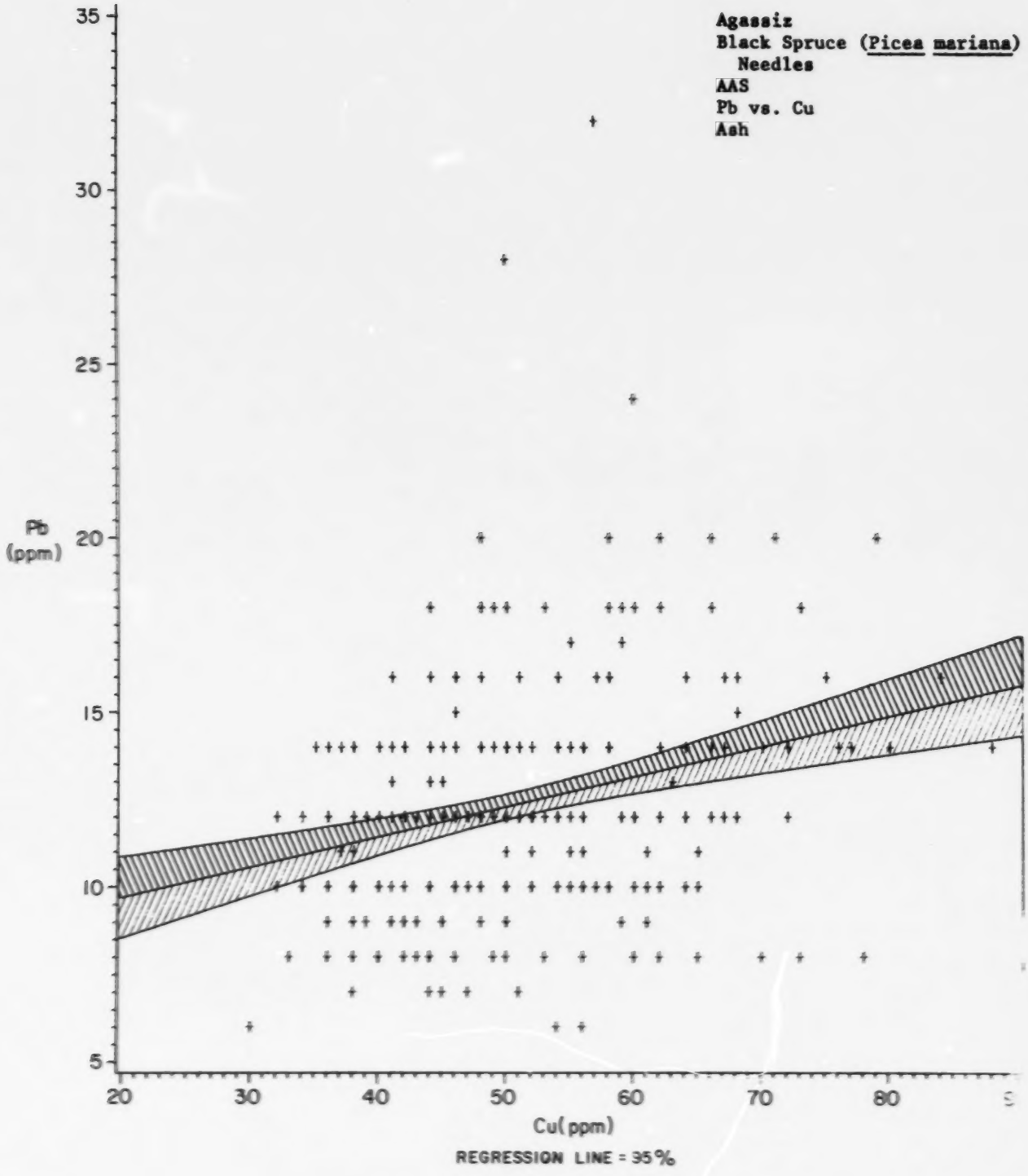

Agassiz
Black Spruce (Picea mariana)
Needles
AAS
Fe vs. Cu (Scale enlarged)
Ash
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
Fe
(ppm)
20
30
40
50
60
70
80
90
Cu(ppm)
REGRESSION LINE = 95 %

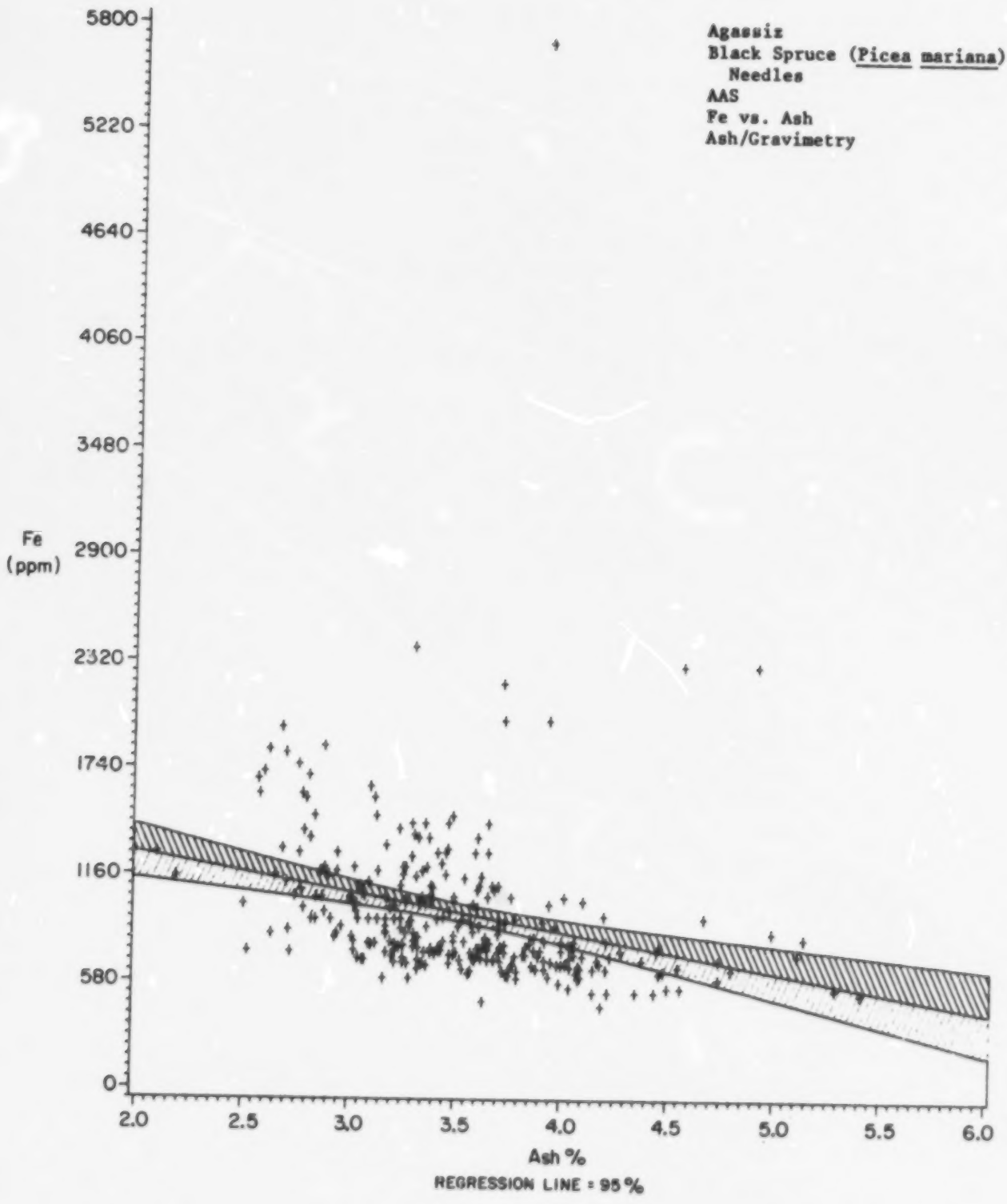

Agassiz
Black Spruce (Picea mariana)
Needles
AAS
Mn vs. Zn
Ash
Mn %
Zn (ppm)
0
400
800
1200
1600
2000
2400
2800
3200
1
2
3
4
5
6
7
8
9
10
REGRESSION LINE = 95%

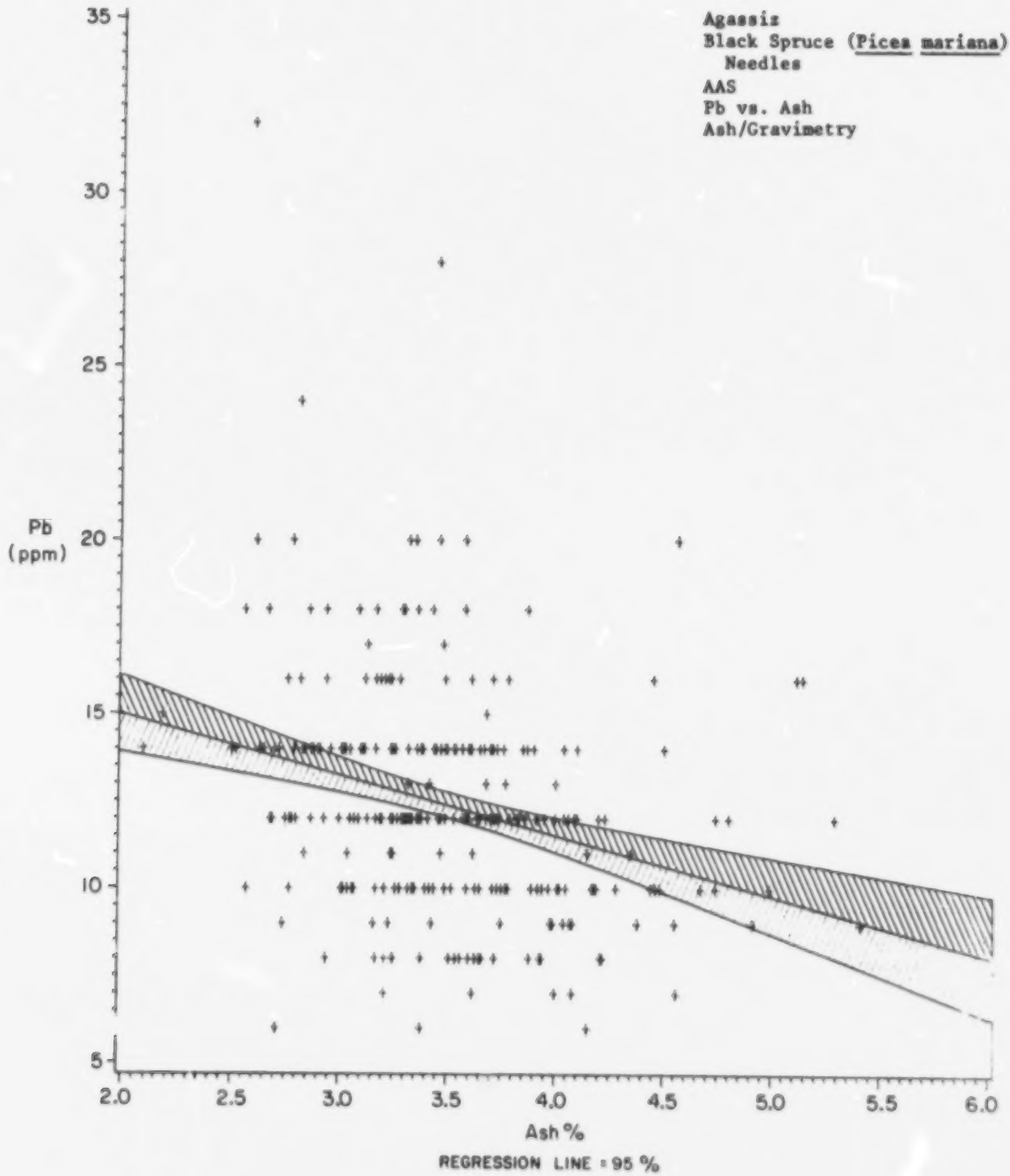

Agassiz
Black Spruce (Picea mariana)
Needles
AAS
Fe vs. Mn
Ash
5800
5220
4640
4060
3480
2900
2320
1740
1160
580
0
Fe
(ppm)
0
1
2
3
4
5
6
7
8
9
10
Mn %
REGRESSION LINE = 95 %

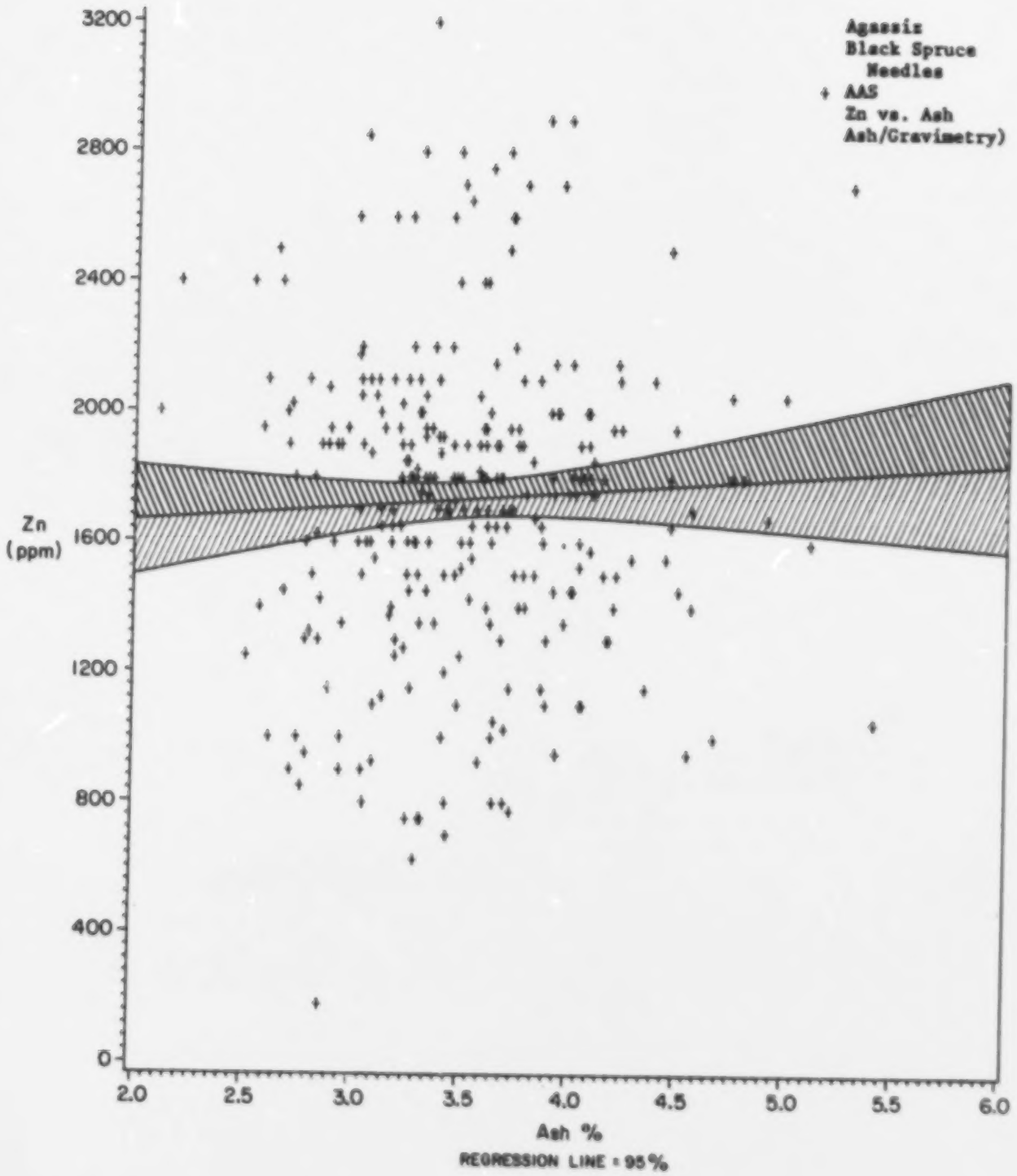

Agassiz
Black Spruce (Picea mariana)
Needles
AAS
Mn vs. Ash
Ash/Gravimetry
Mn %
Ash %
REGRESSION LINE = 95 %

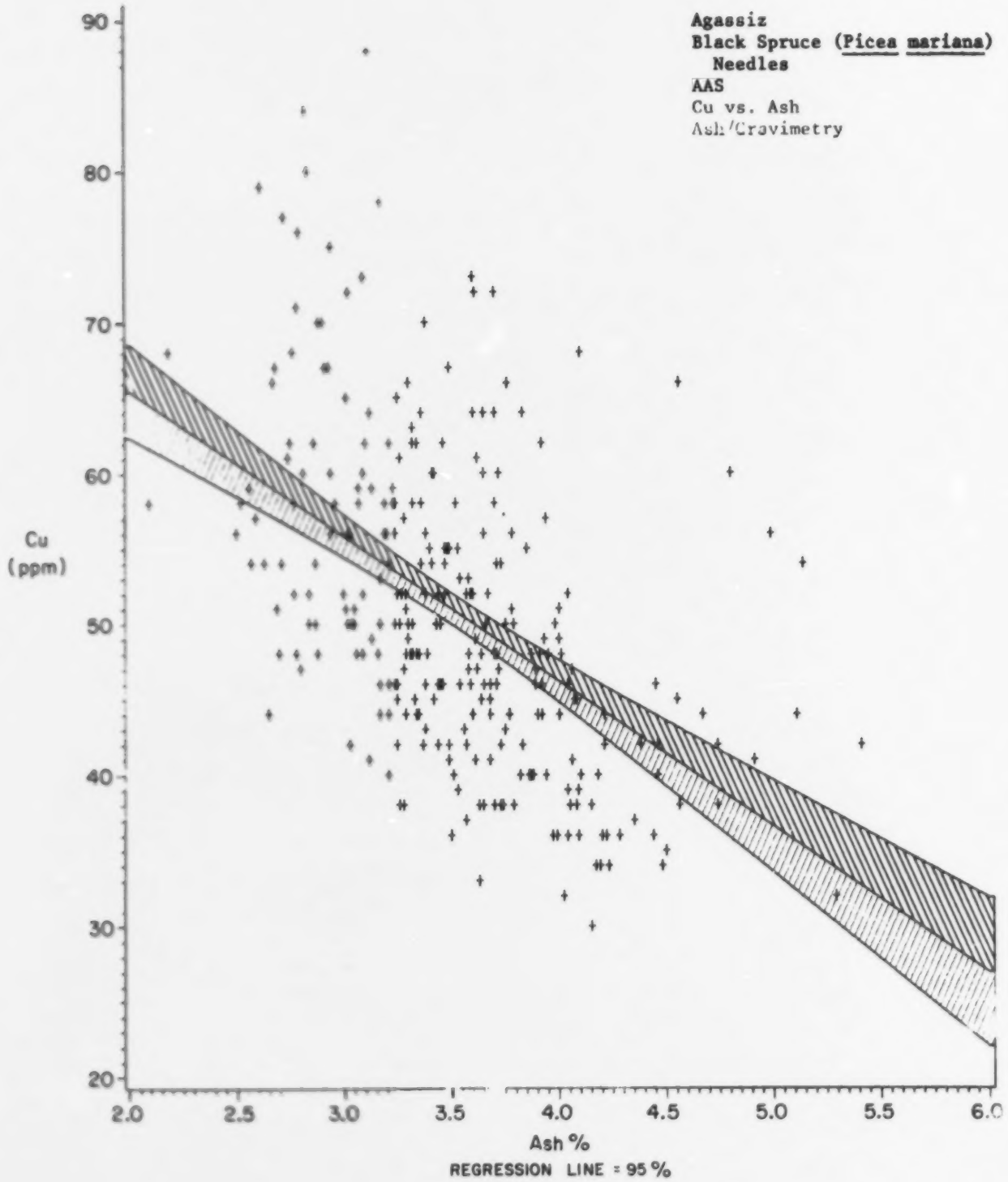

Agassiz
Black Spruce (Picea mariana)
Needles
AAS
Fe vs. Zn
Ash
5800
5220
4640
4060
3480
Fe
(ppm)
2900
2320
1740
1160
580
0
0
400
800
1200
1600
2000
2400
2800
3200
Zn(ppm)
REGRESSION LINE = 95%

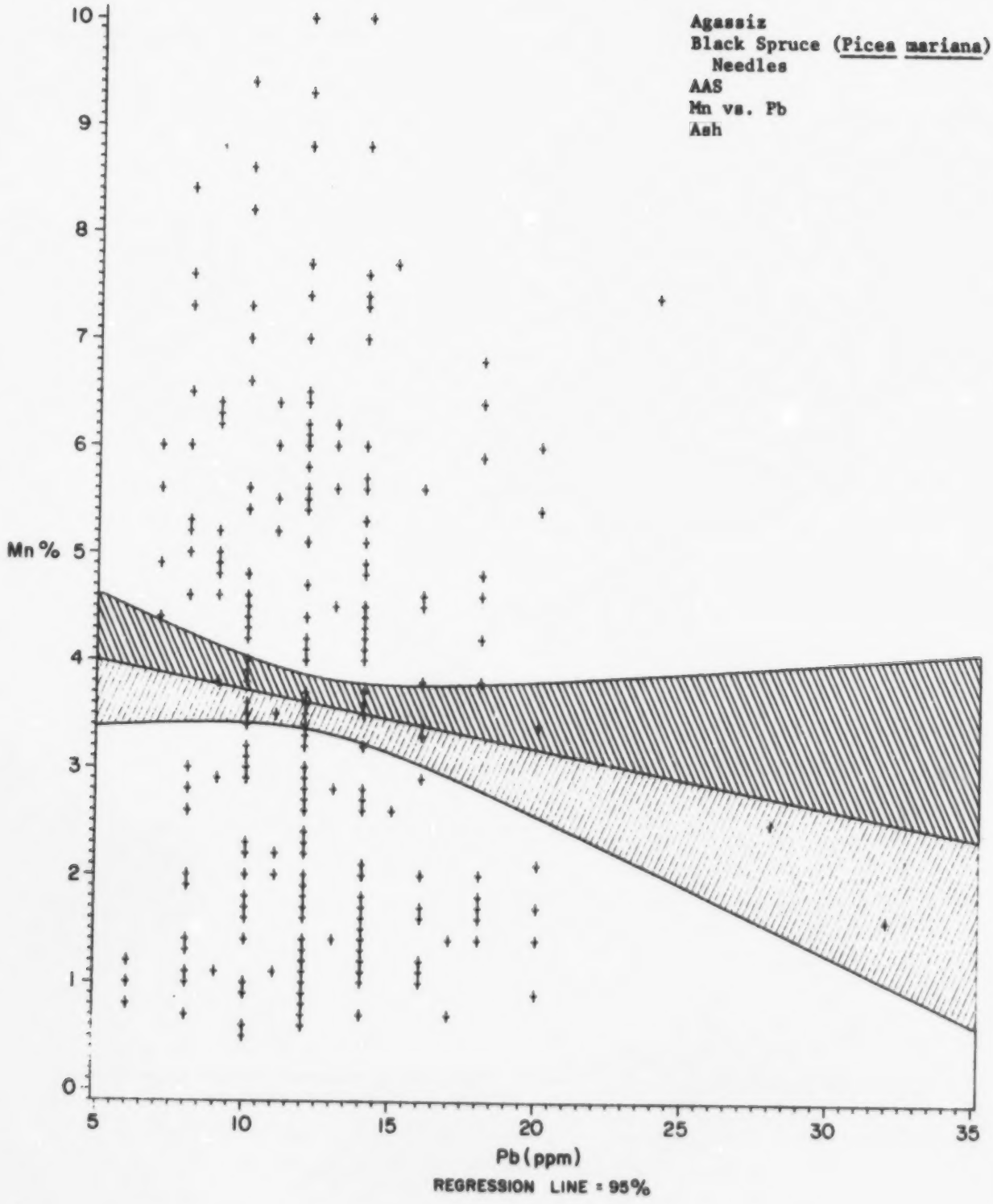

Agassiz
Black Spruce (Picea mariana)
Needles
AAS
Pb vs. Cu
Ash
Pb
(ppm)
35
30
25
20
15
10
5
20
30
40
50
60
70
80
Cu(ppm)
REGRESSION LINE = 35%

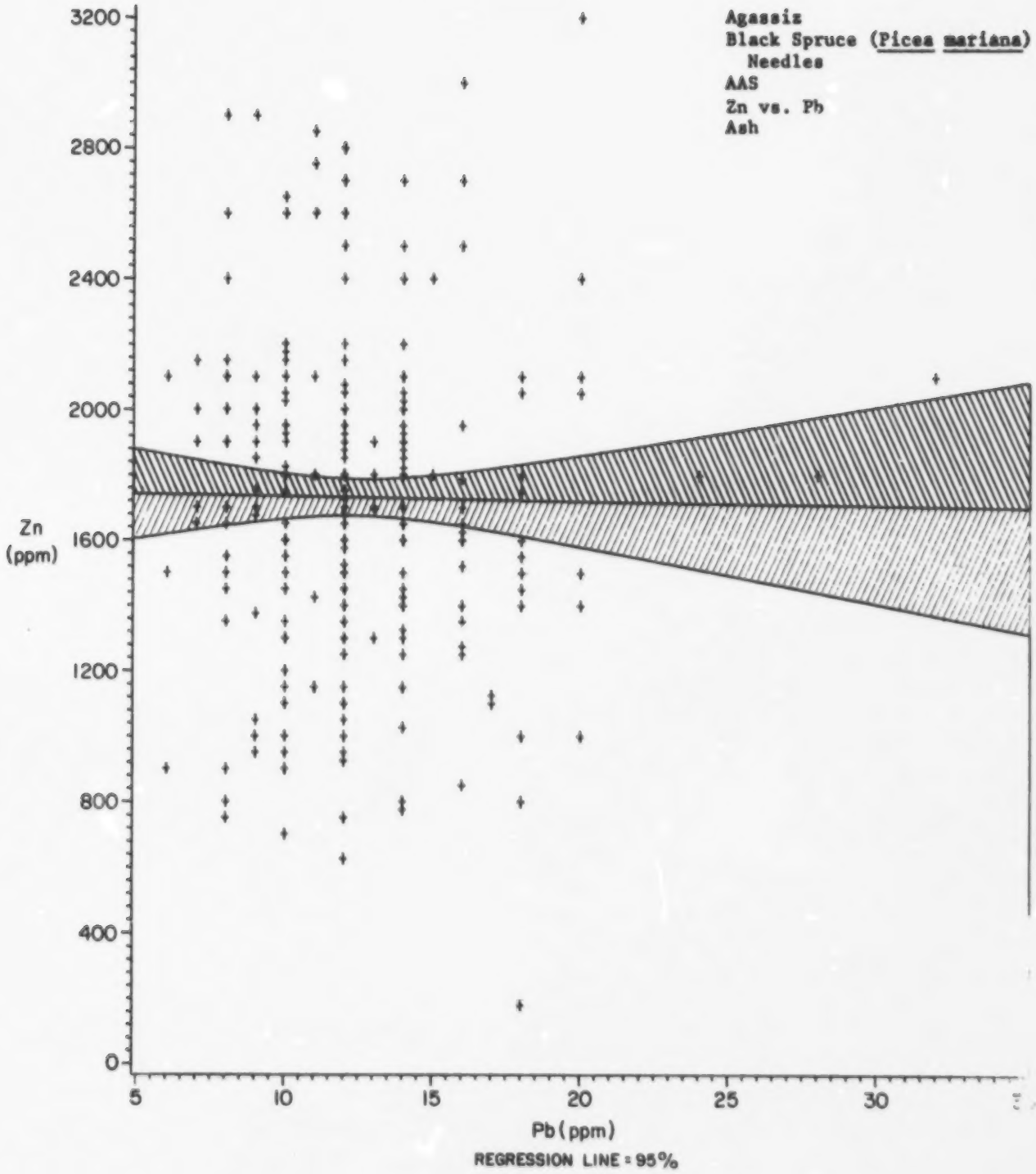

Agassiz
Black Spruce (Picea mariana)
Needles
AAS
Fe vs. Ash
Ash/Gravimetry
5800
5220
4640
4060
3480
2900
2320
1740
1160
580
0
Fe
(ppm)
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
Ash %
REGRESSION LINE = 95 %

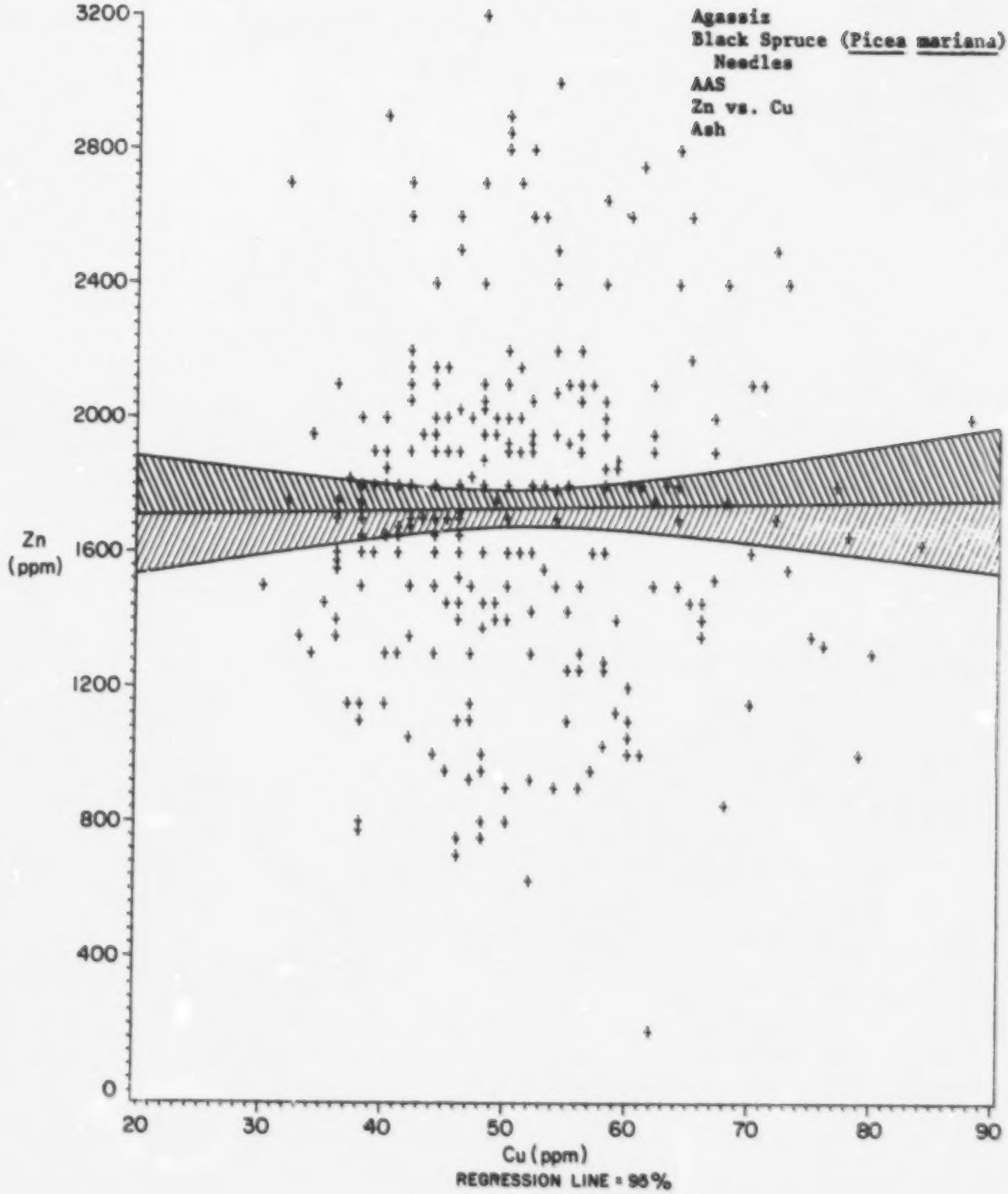

Agassiz
Black Spruce (Picea mariana)
Needles
AAS
Pb vs. Ash
Ash/Gravimetry
Pb
(ppm)
35
30
25
20
15
10
5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
Ash %
REGRESSION LINE = 95 %

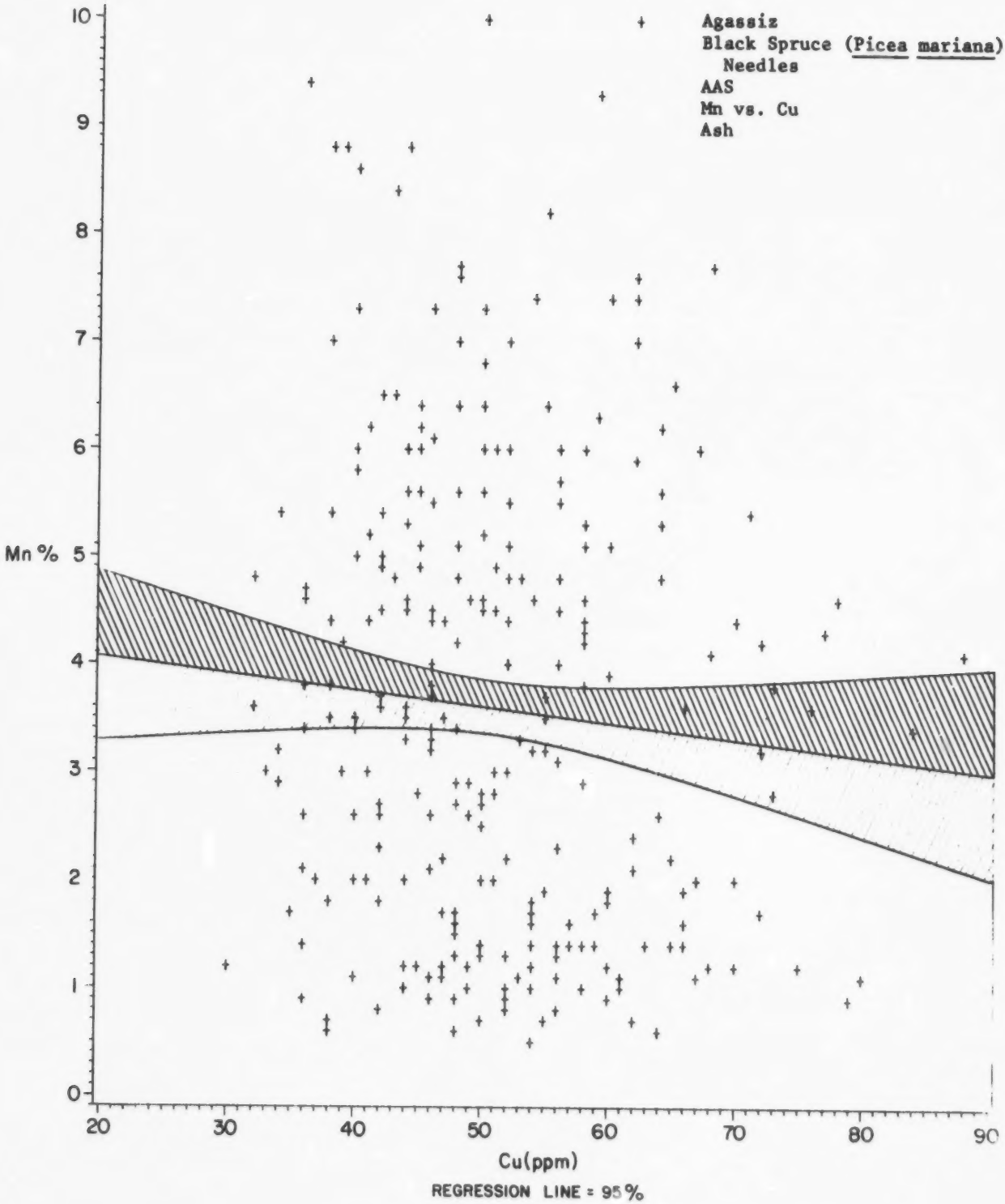

Agassiz
Black Spruce
Needles
AAS
Zn vs. Ash
Ash/Gravimetry)
3200
2800
2400
2000
1600
1200
800
400
0
Zn
(ppm)
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
Ash %
REGRESSION LINE = 95%


Agassiz
Black Spruce (Picea mariana)
Needles
AAS
Cu vs. Ash
Ash/Gravimetry
90
80
70
60
50
40
30
20
Cu
(ppm)
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
Ash %
REGRESSION LINE = 95 %


Agassiz
Black Spruce (Picea mariana)
Needles
AAS
Mn vs. Pb
Ash
Mn %
Pb (ppm)
REGRESSION LINE = 95%


Agassiz
Black Spruce (Picea mariana)
Needles
AAS
Zn vs. Pb
Ash
3200
2800
2400
2000
1600
1200
800
400
0
Zn
(ppm)
5
10
15
20
25
30
Pb (ppm)
REGRESSION LINE = 95%


Agassiz
Black Spruce (Picea mariana)
Needles
AAS
Zn vs. Cu
Ash
3200
2800
2400
2000
1600
1200
800
400
0
Zn (ppm)
20
30
40
50
60
70
80
90
Cu (ppm)
REGRESSION LINE = 95%

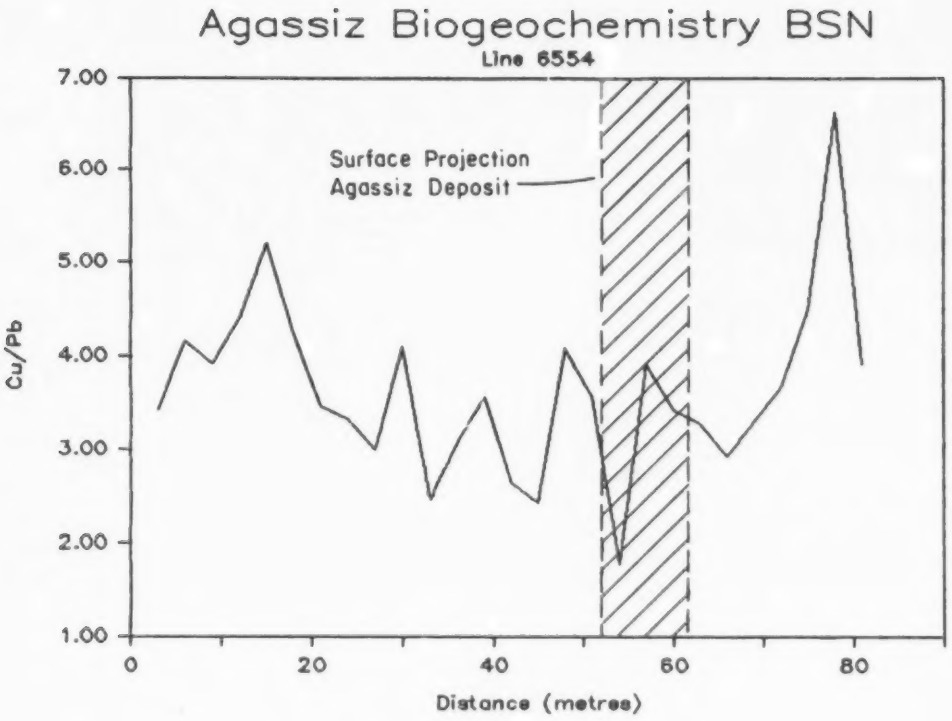

Agassiz
Black Spruce (Picea mariana)
Needles
AAS
Mn vs. Cu
Ash
Mn %
Cu(ppm)
REGRESSION LINE = 95%

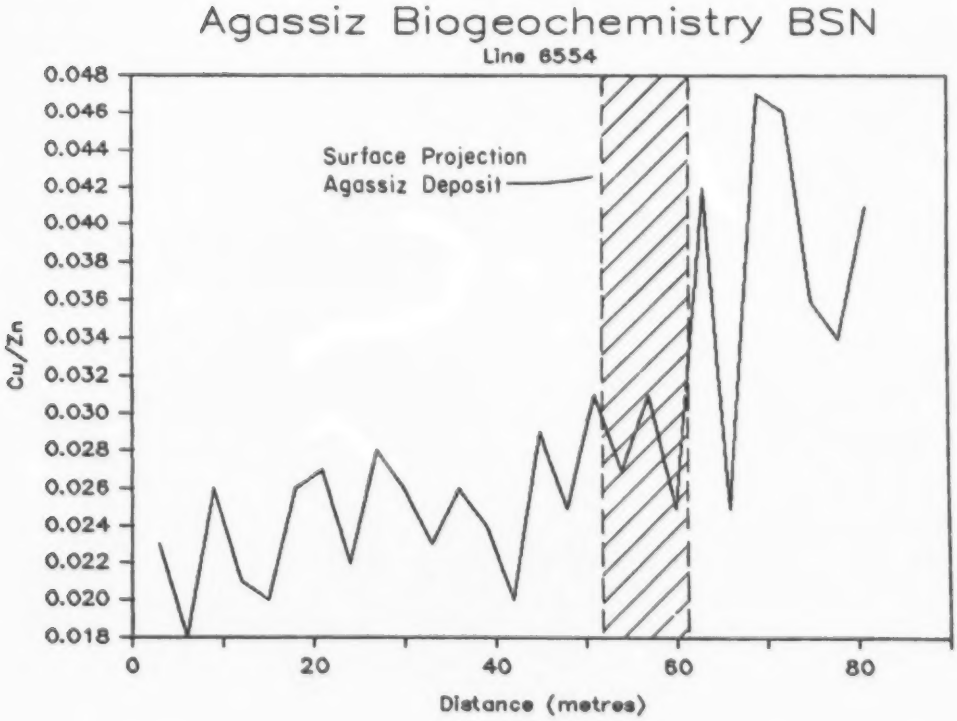
APPENDIX 3 - Part 2

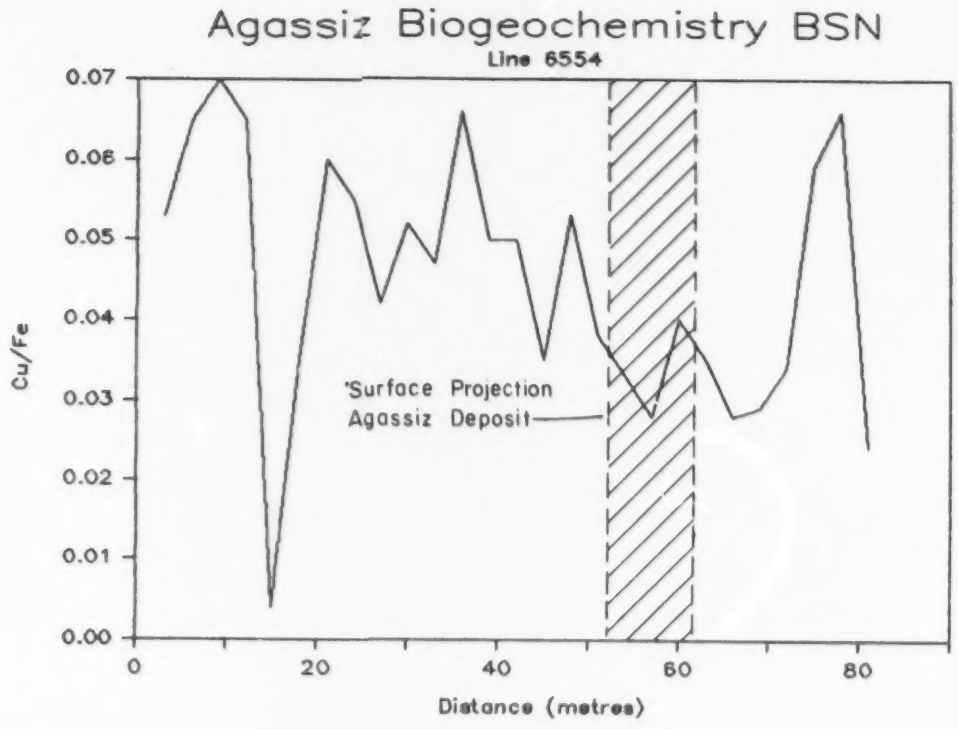
Element Ratio Plots

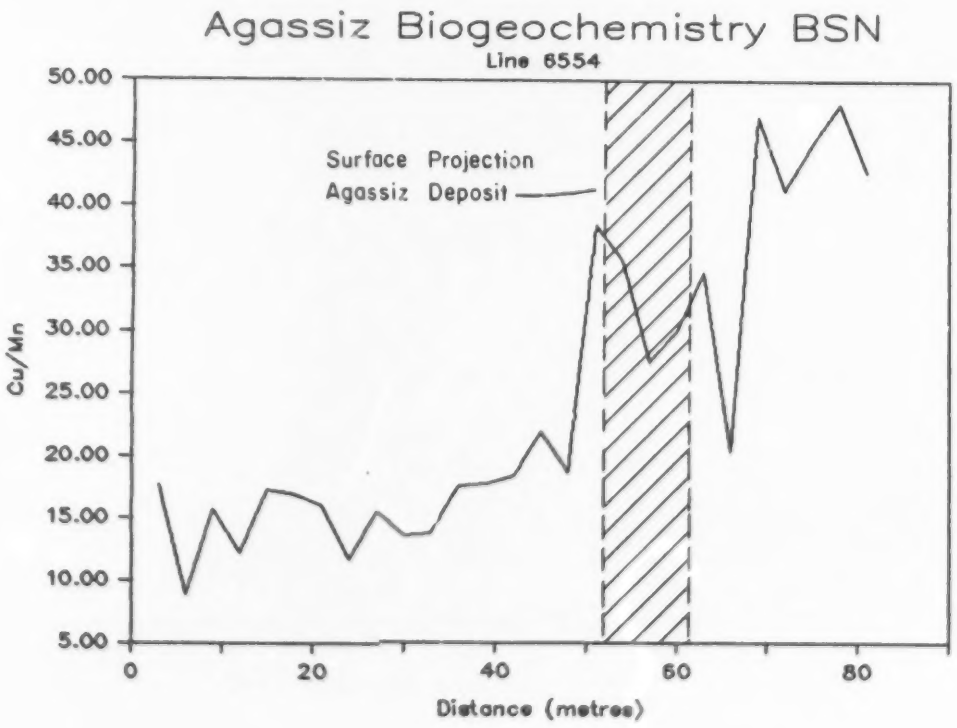
Line 6554

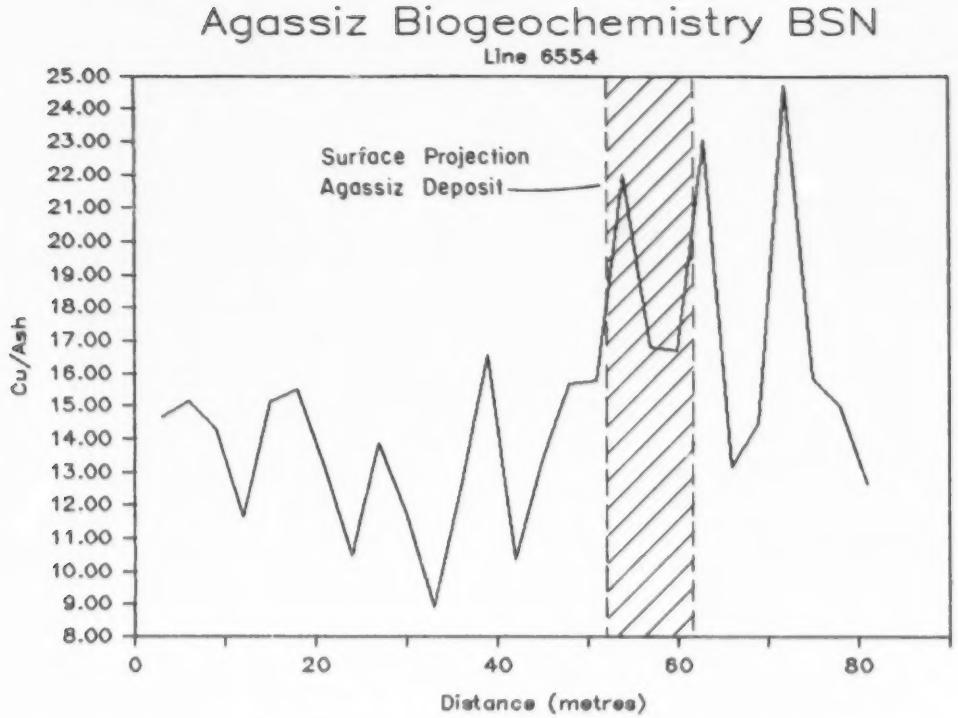
Agassiz Black Spruce Needles and Twigs

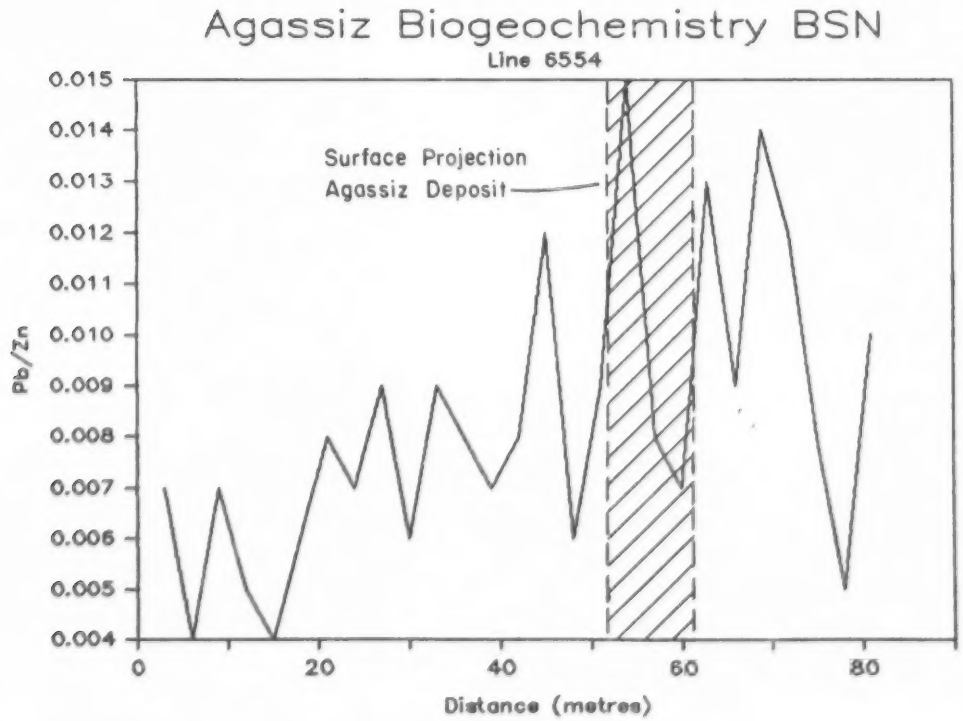

Agassiz Biogeochemistry BSN
Line 6554
Surface Projection
Agassiz Deposit
Cu/Pb
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0
20
40
60
80
Distance (metres)

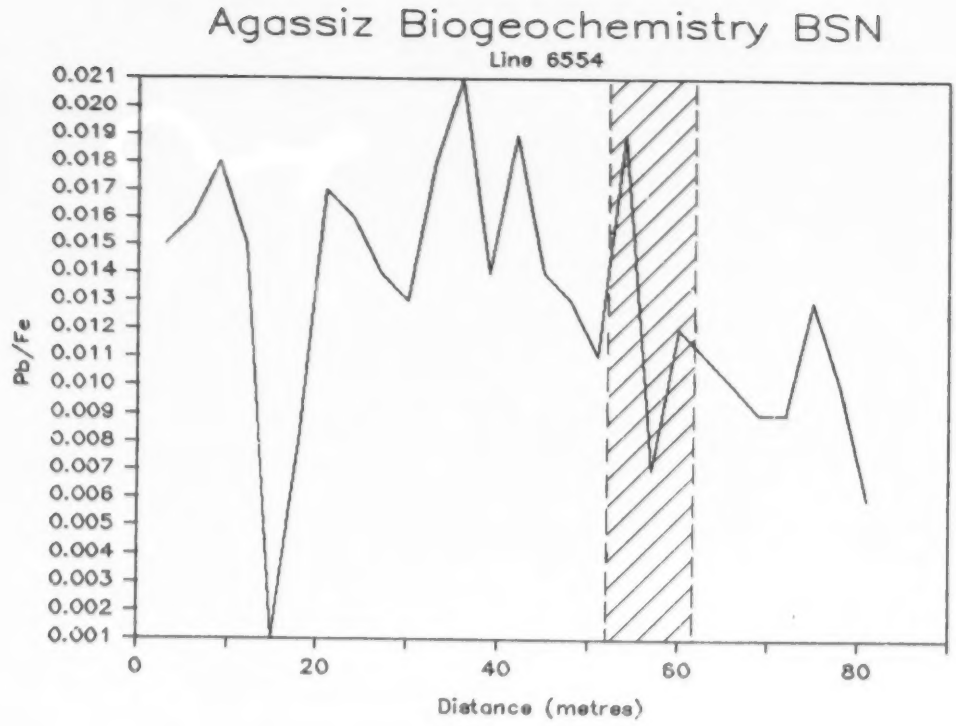

Agassiz Biogeochemistry BSN
Line 6554
Surface Projection
Agassiz Deposit
Cu/Zn
0.048
0.046
0.044
0.042
0.040
0.038
0.036
0.034
0.032
0.030
0.028
0.026
0.024
0.022
0.020
0.018
0
20
40
60
80
Distance (metres)

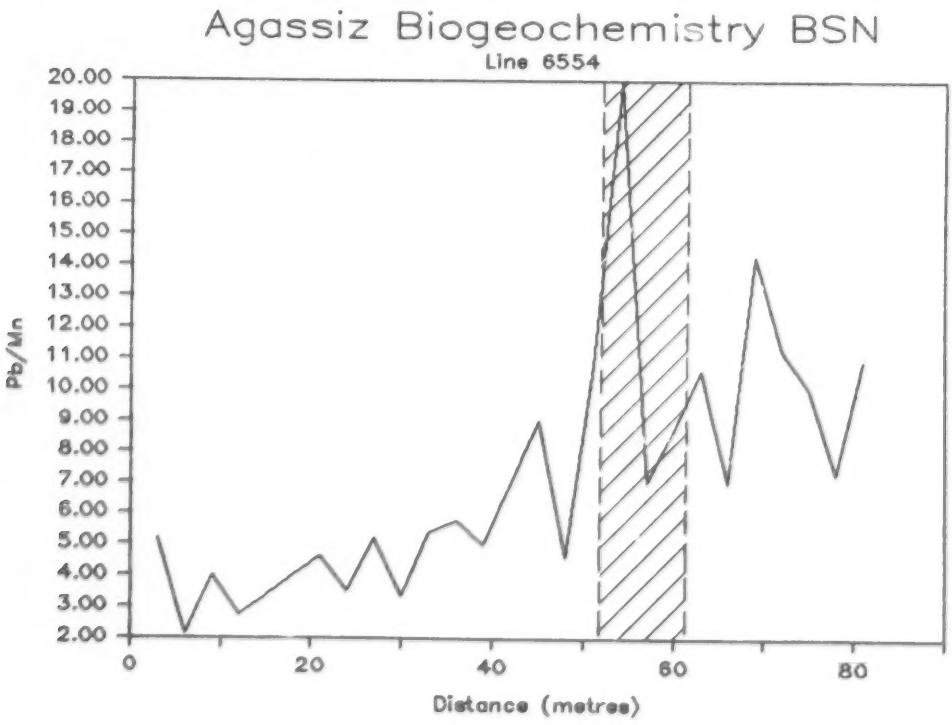

Agassiz Biogeochemistry BSN
Line 6554
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Cu/Fe
Surface Projection
Agassiz Deposit
0
20
40
60
80
Distance (metres)

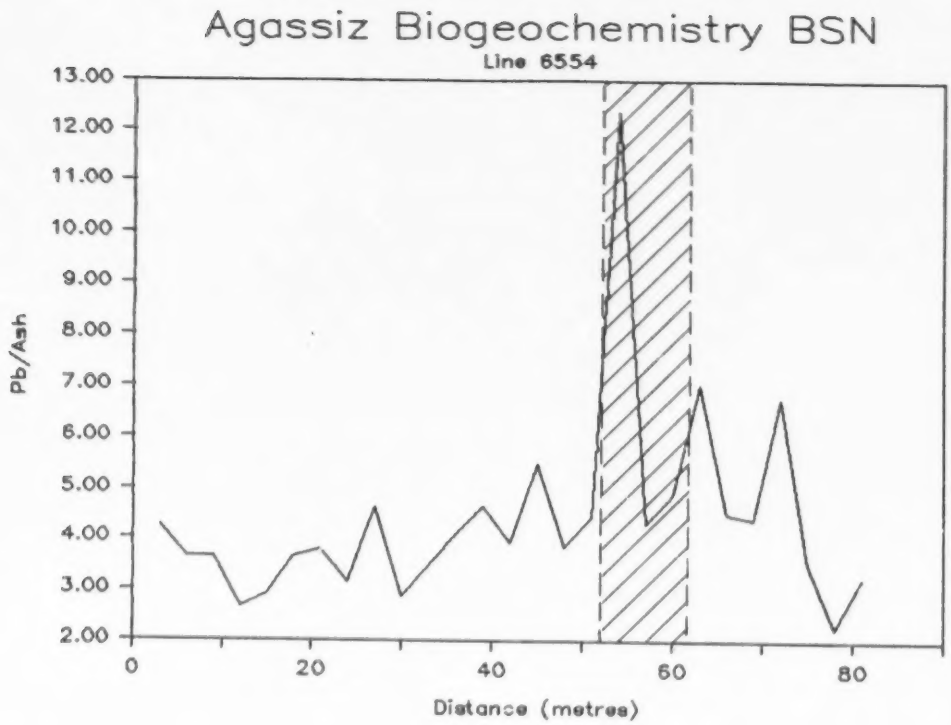

Agassiz Biogeochemistry BSN
Line 6554
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
Cu/Mn
Surface Projection
Agassiz Deposit
0
20
40
60
80
Distance (metres)

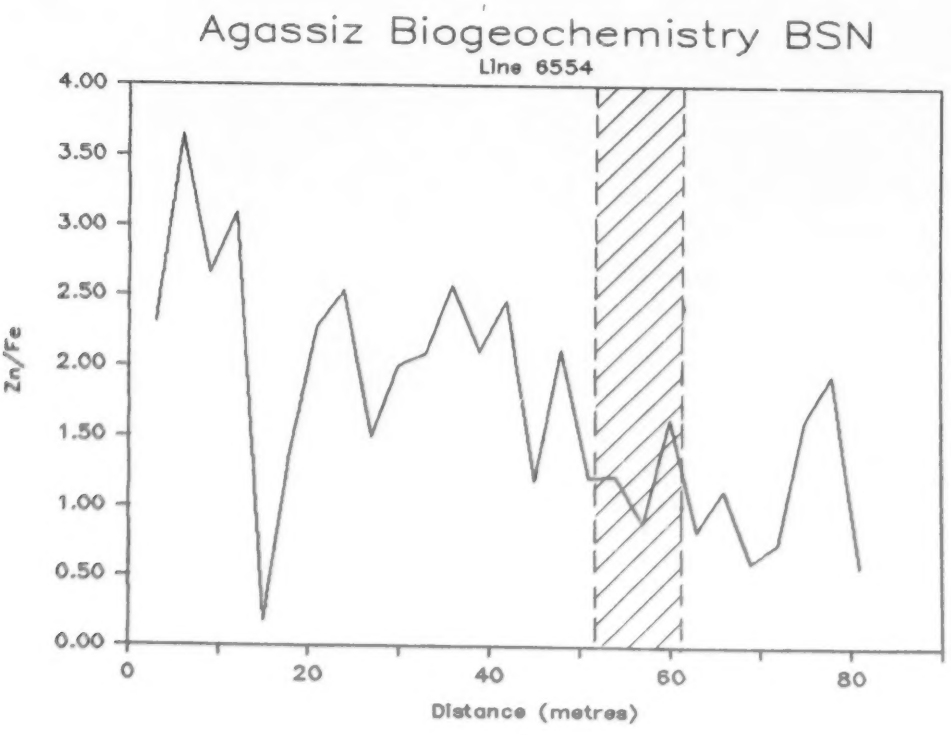

Agassiz Biogeochemistry BSN
Line 6554
Surface Projection
Agassiz Deposit
Cu/Ash
25.00
24.00
23.00
22.00
21.00
20.00
19.00
18.00
17.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
9.00
8.00
0
20
40
60
80
Distance (metres)

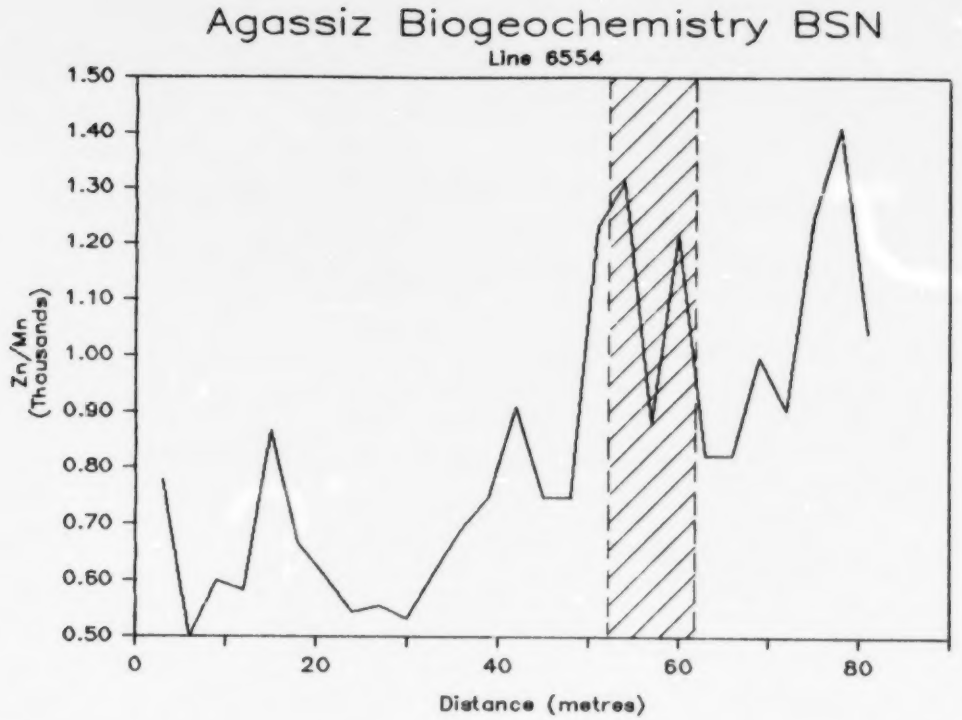

Agassiz Biogeochemistry BSN
Line 6554
Surface Projection
Agassiz Deposit
Pb/Zn
0.015
0.014
0.013
0.012
0.011
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0
20
40
60
80
Distance (metres)

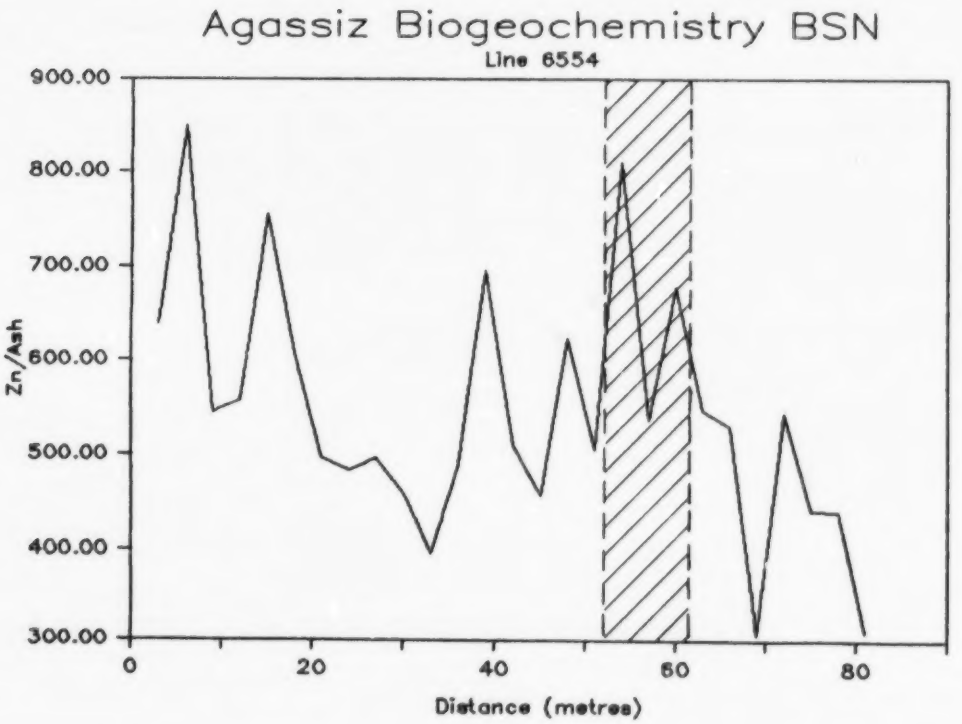

Agassiz Biogeochemistry BSN
Line 6554
Pb/Fe
0.021
0.020
0.019
0.018
0.017
0.016
0.015
0.014
0.013
0.012
0.011
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
20
40
60
80
Distance (metres)

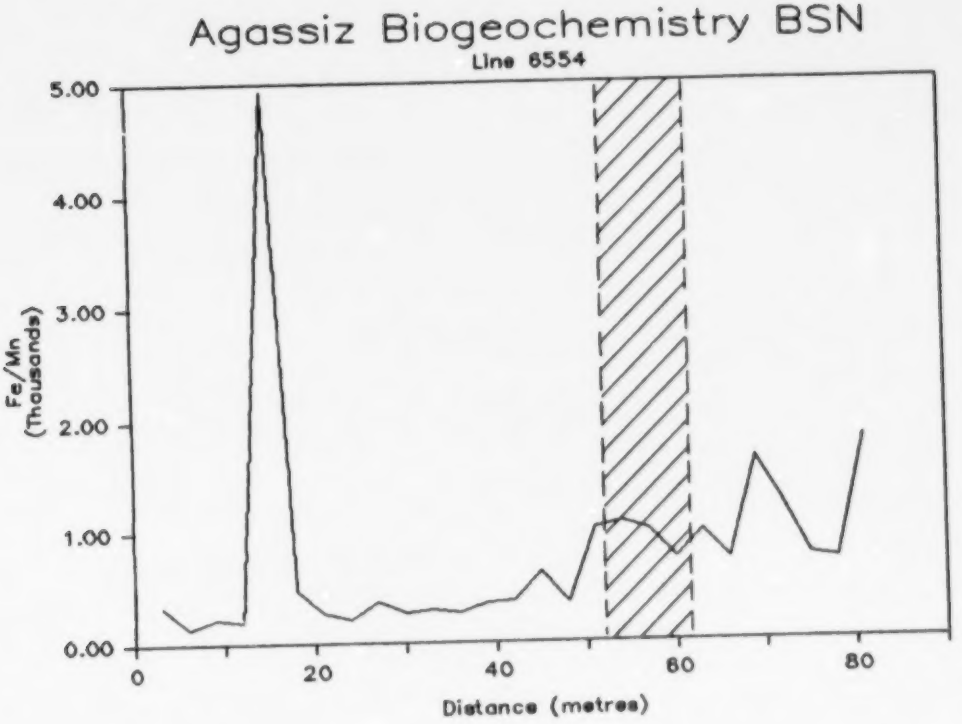

Agassiz Biogeochemistry BSN
Line 6554
Pb/Mn
20.00
19.00
18.00
17.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
0
20
40
60
80
Distance (metres)

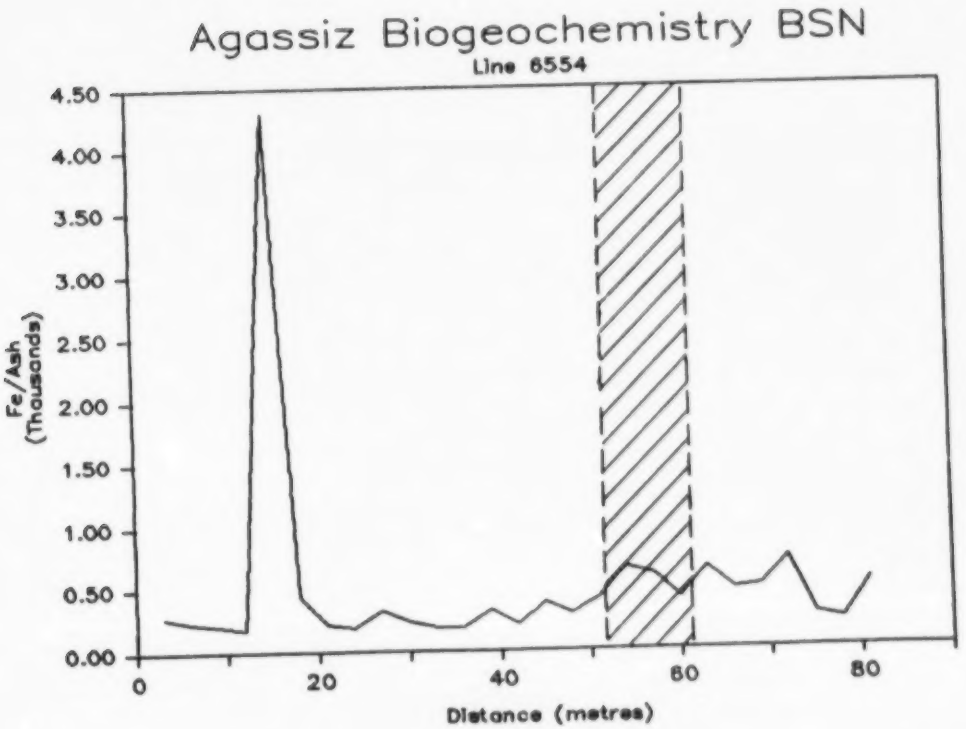

Agassiz Biogeochemistry BSN
Line 6554
13.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
Pb/Ash
0
20
40
60
80
Distance (metres)

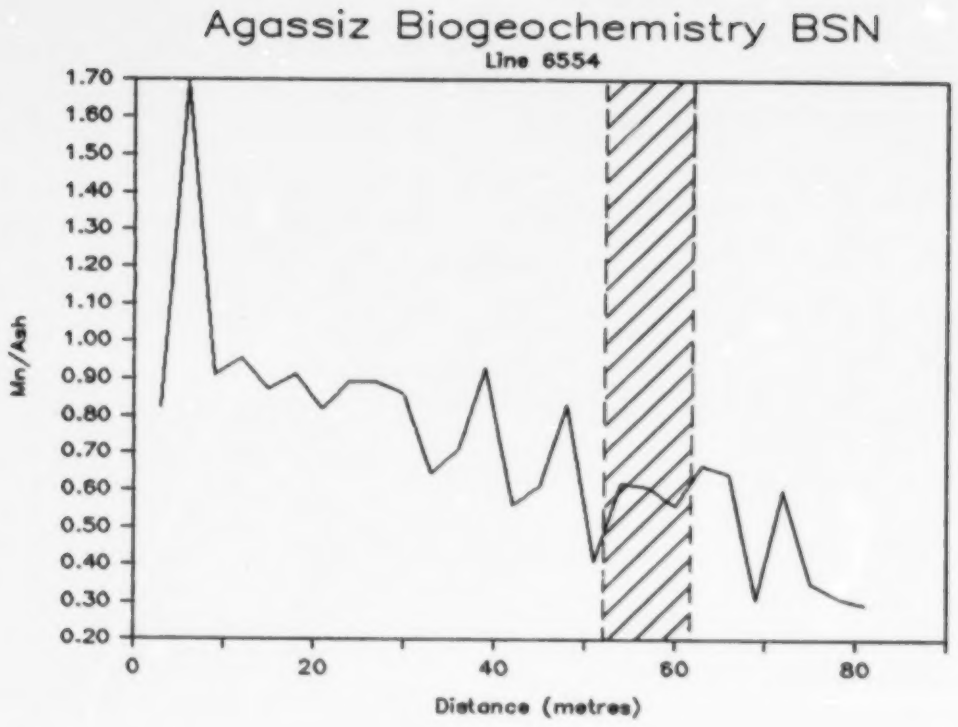

Agassiz Biogeochemistry BSN
Line 6554
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Zn/Fe
0
20
40
60
80
Distance (metres)

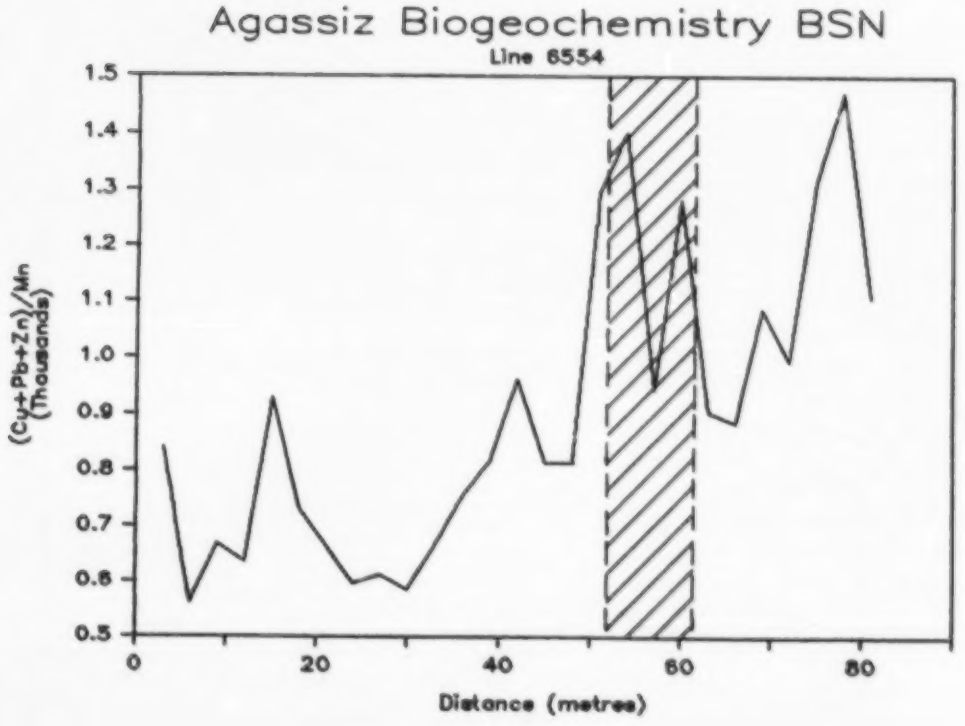

Agassiz Biogeochemistry BSN
Line 6554
Zn/Mn (Thousands)
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0
20
40
60
80
Distance (metres)


Agassiz Biogeochemistry BSN
Line 6554
Zn/Ash
900.00
800.00
700.00
600.00
500.00
400.00
300.00
0
20
40
60
80
Distance (metres)


Agassiz Biogeochemistry BSN
Line 6554
5.00
4.00
3.00
2.00
1.00
0.00
Fe/Mn (Thousands)
0
20
40
60
80
Distance (metres)


Agassiz Biogeochemistry BSN
Line 6554
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Fe/Ash (Thousands)
0
20
40
60
80
Distance (metres)


Agassiz Biogeochemistry BSN
Line 6554
Mn/Ash
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0
20
40
60
80
Distance (metres)


Agassiz Biogeochemistry BSN
Line 6554
(Cu+Pb+Zn)/Mn
(Thousands)
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0
20
40
60
80
Distance (metres)

APPENDIX 4
Spearman and Kendall correlation coefficient matrices

Spearman and Kendall nonparametric correlation coefficients black spruce (Picea mariana) twigs (n = 309) Agassiz deposit

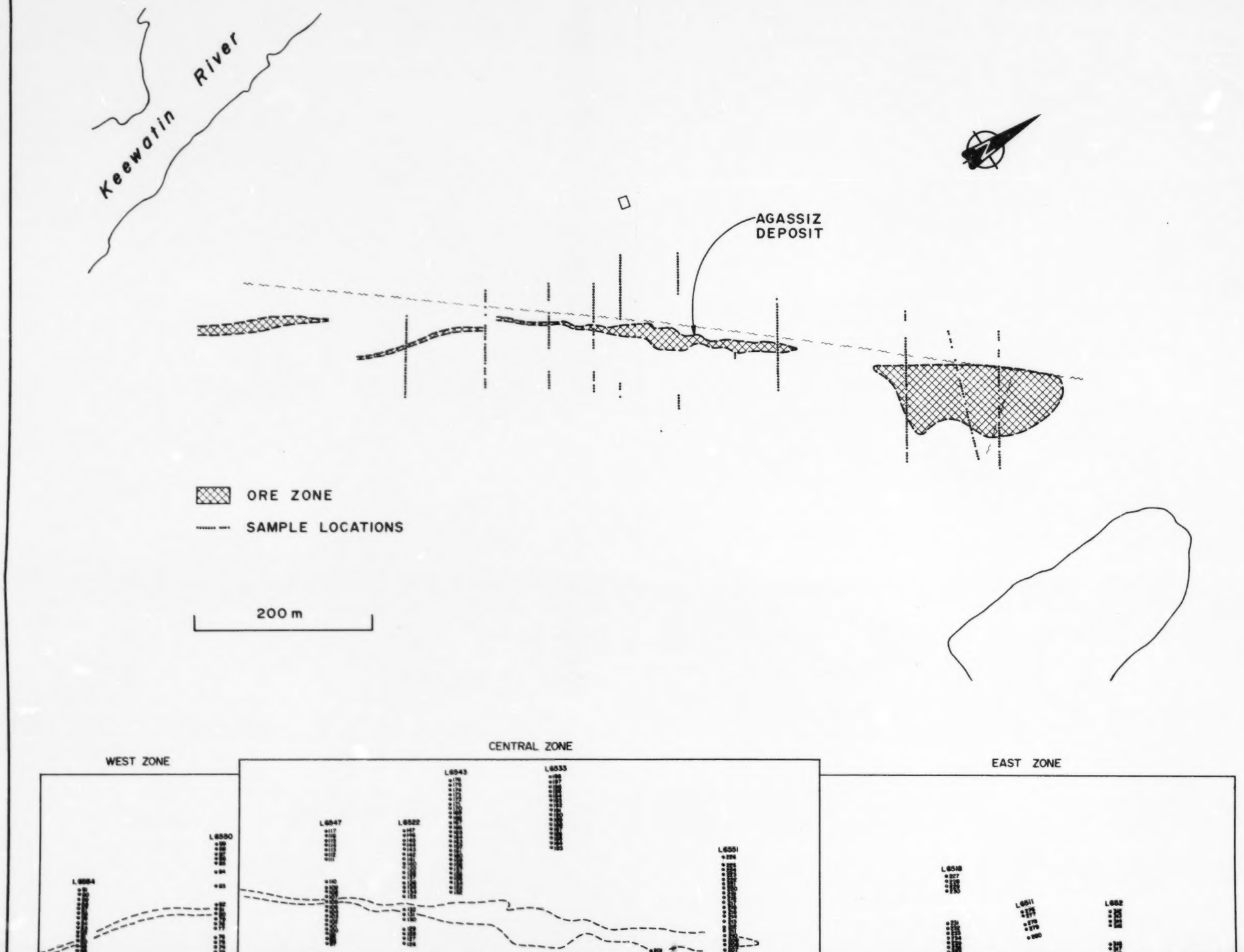
	As	Au		As	Au
Spearman			Kendall		
As	1.00000 0.0000	0.36052 0.0001	As	1.00000 0.0000	0.26099 0.0001
Au	0.36052 0.0001	1.00000 0.0000	Au	0.26099 0.0001	1.00000 0.0000

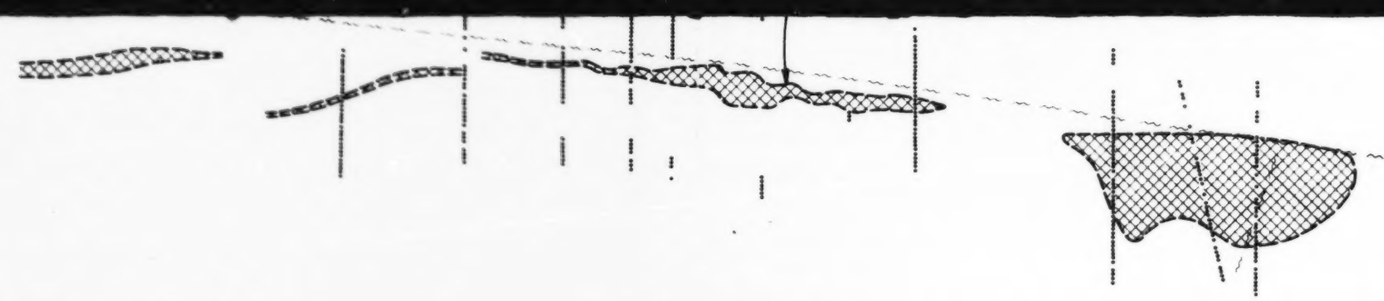
Spearman nonparametric correlation coefficients black spruce (Picea mariana) needles (n=292) Agassiz deposit

SAMPLE	Cu	Pl	Zn	Fe	Mn	Ash
Cu	1.0000 0.0000	0.26250 0.0001	0.04195 0.4752	0.43647 0.0001	-0.08022 0.1716	-0.53855 0.0001
Pb	0.26250 0.0001	1.00000 0.0000	-0.06189 0.2919	0.38313 0.0001	-0.08169 0.1638	-0.29795 0.0001
Zn	0.04195 0.4752	-0.06189 0.2919	1.00000 0.0000	-0.22519 0.0001	0.40619 0.0001	0.02567 0.6622
Fe	0.43647 0.0001	0.38313 0.0001	-0.22519 0.0001	1.00000 0.0000	-0.30006 0.0001	-0.51864 0.0001
Mn	-0.08022 0.1716	-.08169 0.1638	0.40617 0.0001	-0.30006 0.0001	1.00000 0.0000	0.04104 0.4848
Ash	-0.53855 0.0001	-0.29795 0.0001	0.02567 0.6622	-0.51864 0.0001	0.04104 0.4848	1.00000 0.0000

Kendall nonparametric correlation coefficients, black spruce (Picea mariana) needles (n = 292) Agassiz deposit

SAMPLE	Cu	Pb	Zn	Fe	Mn	Ash
Cu	1.0000	0.19114	0.03082	0.30676	-0.05314	-0.38582
	0.0000	0.0000	0.4465	0.0001	0.1863	0.0001
Pb	0.19114	1.00000	-0.04591	0.28656	-0.06016	-0.21717
	0.0000	0.0000	0.2812	0.0001	0.1550	0.0000
Zn	0.03082	-0.04591	1.00000	-0.15465	0.29309	0.01780
	0.4465	0.2812	0.0000	0.0001	0.0001	0.6560
Fe	0.30676	0.28656	-0.15465	1.00000	-0.20639	-0.37262
	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001
Mn	-0.05314	-.06016	0.29309	-0.20639	1.00000	0.02878
	0.1863	0.1550	0.0001	0.0000	0.0000	0.4683
Ash	-0.38582	-0.21717	0.01780	-0.37262	0.02878	1.00000
	0.0001	0.0001	0.6560	0.0001	0.4683	0.0000

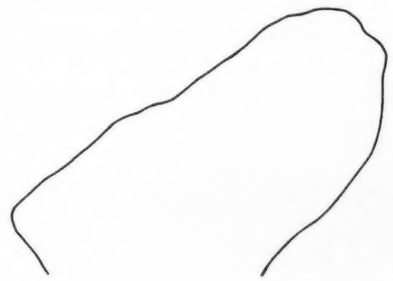

Keewatin River
AGASSIZ DEPOSIT
ORE ZONE
SAMPLE LOCATIONS
200 m
WEST ZONE
CENTRAL ZONE
EAST ZONE
L6584
L6580
L6547
L6522
L6543
L6533
L6551
L6518
L6511
L6502



ORE ZONE

SAMPLE LOCATIONS

200 m



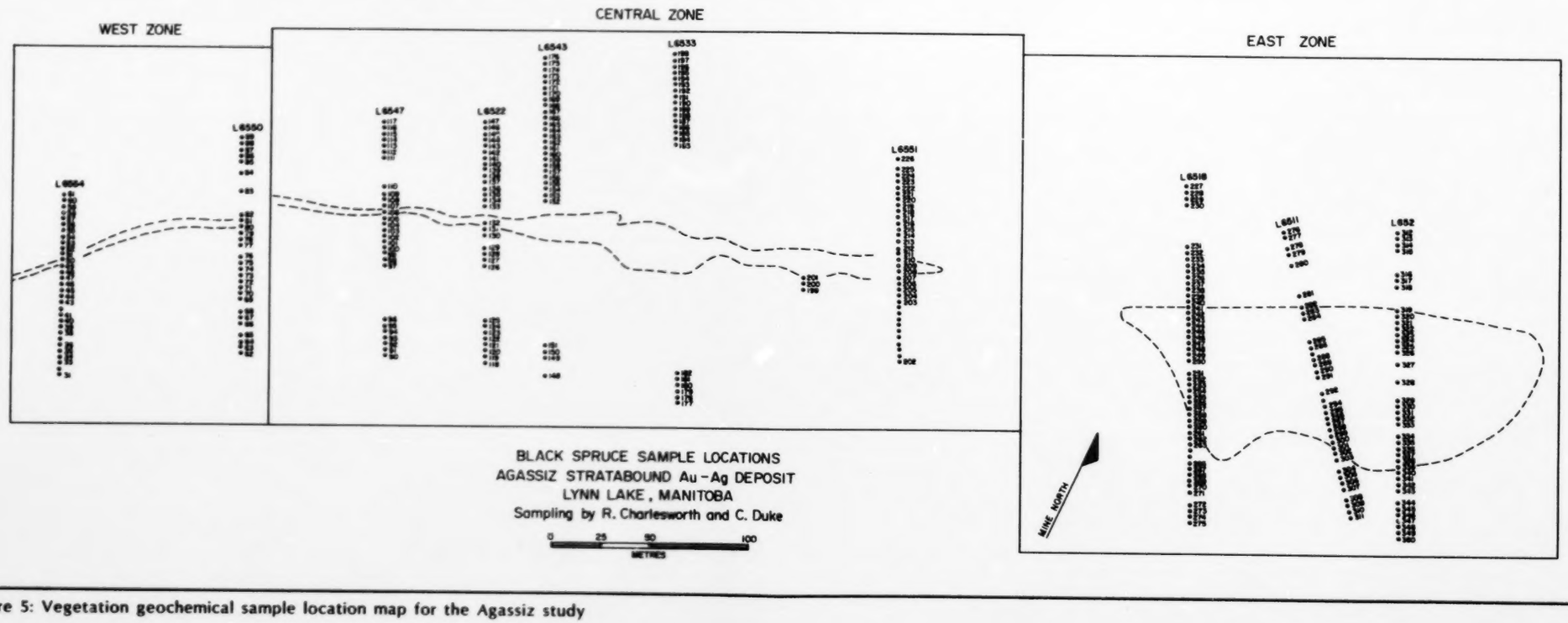


Figure 5: Vegetation geochemical sample location map for the Agassiz study